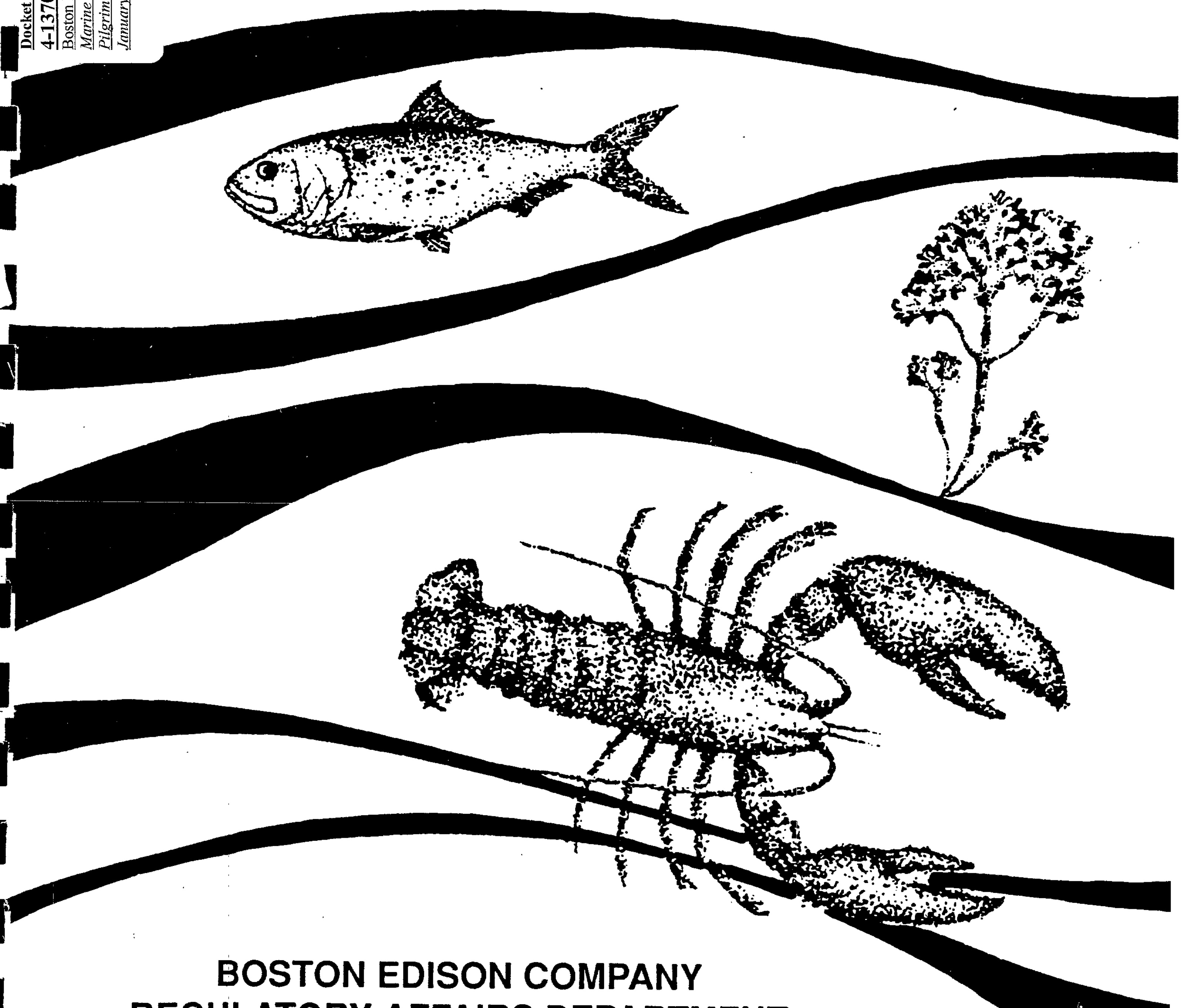
23800 Intake - case studies - Pilgrim

marine ecology studies

Related to Operation of Pilgrim Station

SEMI-ANNUAL REPORT NUMBER 53
JANUARY 1998 - DECEMBER 1998



BOSTON EDISON COMPANY
REGULATORY AFFAIRS DEPARTMENT

220 p.

Boston Edison

APR 16 1999

MARINE ECOLOGY STUDIES

RELATED TO OPERATION OF PILGRIM STATION

SEMI-ANNUAL REPORT NO. 53

REPORT PERIOD: JANUARY 1998 THROUGH DECEMBER 1998

DATE OF ISSUE: APRIL 30, 1999

Compiled and Reviewed by: Robert D. Anderson
Robert D. Anderson
Principal Marine Biologist

Regulatory Affairs Department
Boston Edison Company
Pilgrim Nuclear Power Station
Plymouth, Massachusetts 02360

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A BEC ENERGY COMPANY

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April 12, 1999
BECo Ltr. 5.99.015

Planning and Administration (SPA)
U. S. Environmental Protection Agency
P.O. Box 8127
Boston, MA 02114-8127

NPDES PERMIT MARINE ECOLOGY MONITORING REPORT

Dear Sirs:

In accordance with Part 1, Paragraphs A.8.b & e, and Attachment A, Paragraph 1.F, of the Pilgrim Nuclear Power Station NPDES Permit No. MA0003557 (federal) and No. 359 (state), Semi-Annual Marine Ecology Report No. 53 is submitted. This covers the period from January through December, 1998.

J.F. Alexander
Regulatory Relations
Group Manager

RDA/cls
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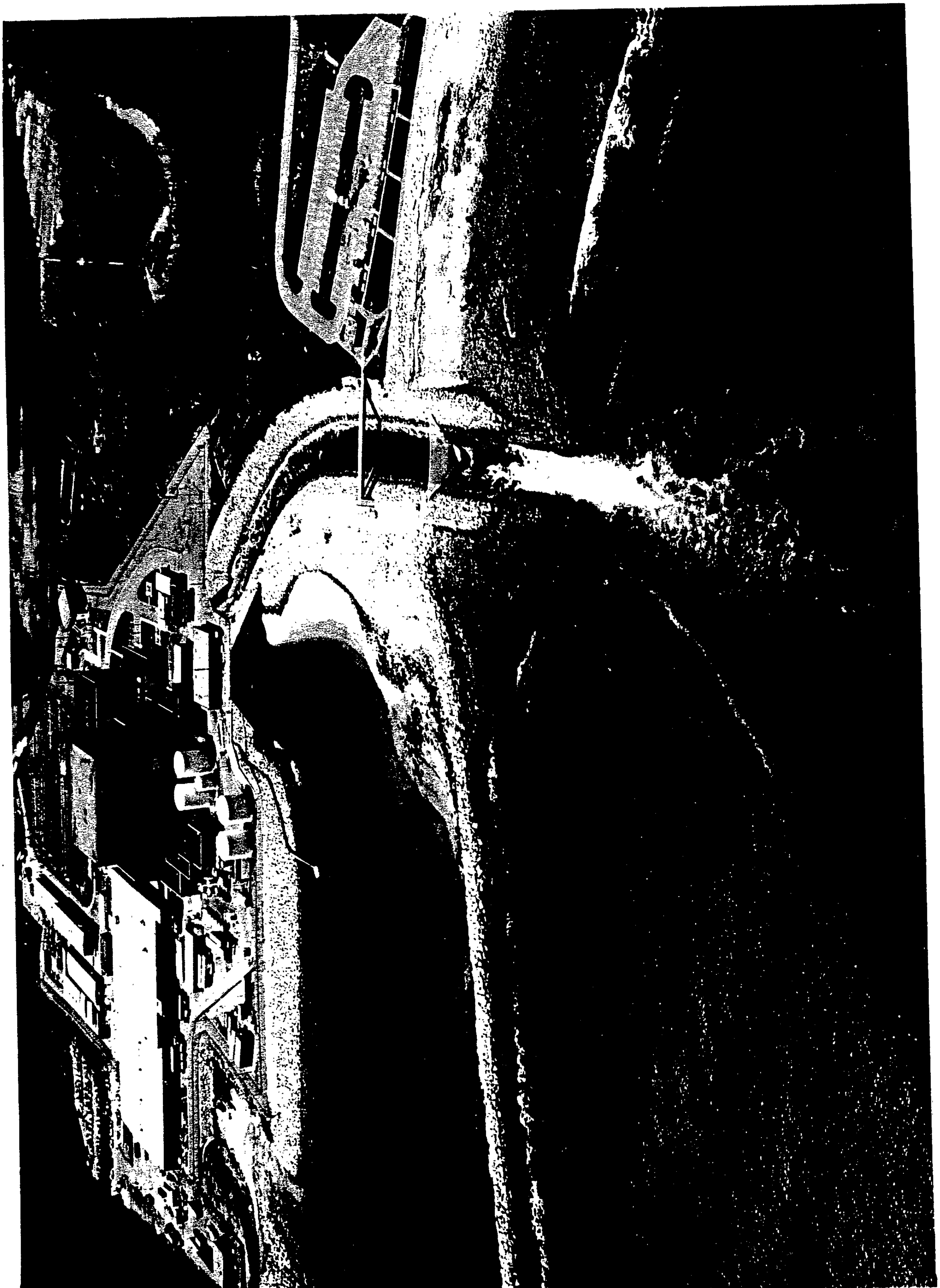
Attachment: Semi-Annual Marine Ecology Report No. 53



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SUMMARY

Highlights of the Environmental Surveillance and Monitoring Program results obtained over this reporting period (January -December 1998) are presented below. (Note: PNPS was operating at high power level during most of January - December 1998).

Marine Fisheries Monitoring:

1. In the April - August/November 1998 shorefront sportfish survey at Pilgrim Station there were 1,877 angler visits and 1,553 fishes recorded for a catch rate of 0.83. Striped bass (72.3%) and bluefish (27.2%) dominated the sportfish catch. The presence of a strong thermal discharge component attracted fish during most of 1990 - 1998 which resulted in good sportfishery success compared with outage and low power years.

2. During late August - December 1998 fish observational dive surveys, fish species were observed in the thermal effluent area. Striped bass and tautog were the most numerous fishes seen, being abundant in the Pilgrim discharge current. Striped bass observations peaked in early September while tautog were consistent throughout the summer into early November. Data from the dive and sportfish surveys reveal that certain species are attracted to either the elevated water temperatures (spring and fall) or current. This places them at risk of impact from temperature aberrations, chemical releases, and potential gas bubble disease mortalities. As such, some form of direct visual monitoring is useful.

3. Winter flounder tagging in the Plymouth Bay vicinity to estimate adult population size and Pilgrim Station impact has accounted for 22,476 fish with 896 (4.0%) tag returns from 1993-1998, resulting in pool population estimation precision. The 1998 population estimate based on an Area Swept Method (trawling) for the Plymouth Bay area was 264,812 adult winter flounder (age 3+). This equates to roughly a 29% adult population impact from PNPS entrainment of 88,800,000 flounder larvae (77,428 equivalent adults) although area - swept estimate variability is high. Continuation of this study may not yield a more accurate or precise estimate of population size. More years of study to define the impact of Pilgrim Station on this species may not provide a definitive answer.

4. Rainbow smelt egg restocking of the Jones River (Kingston) to mitigate the high PNPS smelt impingements in December 1993 (5,100 fish) /1994 (5,300 fish) accounted for 1,800,000 fertilized eggs being transplanted in 1994/1995. Once hatched, these eggs supplemented those produced by the river's spawning population of this species. Smelt impingement has the potential of impacting the local smelt population and was further mitigated in 1996/1997/1998 by improving the smelt spawning habitat in the Jones River to enhance egg survival, through the use of several dozen specially designed egg collecting trays. Future Jones River and other local smelt spawning habitat enhancements will also consider improving water quality.

Impingement Monitoring:

1. The mean January - December 1998 impingement collection rate was 1.30 fish/hr. The rate ranged from 0.09 fish/hr (July) to 5.22 fish/hr (March) with Atlantic silverside comprising 51.6% of the catch, followed by winter flounder 13.1%, Atlantic menhaden 8.7% and rainbow smelt 6.8%. Fish impingement rates in 1989 - 1998 were several times higher than in 1984, 1987 and 1988 when Pilgrim Station outages had both circulating water pumps off and reduced pumping capacity for long periods of time.

2. The March/April 1998 Atlantic silverside impingement accounted for 89% of this species' annual collection.

3. The mean January - December 1998 invertebrate collection rate was 1.11+/hr with blue mussel and sevenspine bay shrimp dominating. Longfin squid and green crabs accounted for 15% of the catch. Twenty-four American lobsters were sampled. The invertebrate impingement rates in 1989 - 1998 were similar to those recorded at Pilgrim Station during the 1987 and 1988 outage years, despite much lower circulating water pump availability in these outage years.

4. Impinged fish initial survival in the Pilgrim Station intake sluiceway was approximately 32% during static screen washes and 51% during continuous washes. Four of the dominant species showed greater than 50% survival overall.

Three observations of the discharge, near-shore acute impact zones were performed during this reporting period. Denuded, sparse, and stunted zone boundaries were indistinguishable during September 1987 - June 1989 discharge surveys as a result of the PNPS extended shutdown. However, these surveys did note impact zone boundaries in fall 1989 - 1998 primarily because two circulating water pumps were in operation most of the time resulting in maximum discharge current flow. The scouring impact area in 1998 varied from 1,437 m^2 (March) to 2,469 m^2 (October). Except for October, the 1998 denuded and total affected zones were fairly typical seasonally, despite heavy mussel settlement and high PNPS operating capacity.

Entrainment Monitoring:

1. A total of 40 species of fish eggs and/or larvae were found in the January - December 1998 entrainment collections: 18 eggs, 40 larvae.

2. Seasonal egg collections for 1998 were dominated by yellowtail flounder, fourbeard rockling, American plaice and Atlantic cod (winter - early spring); Atlantic mackerel and labrids (late spring - early summer); rockling/hake, windowpane and labrids (late summer - autumn).

3. Seasonal larvae collections for 1998 were dominated by sculpin, rock gunnel and sand lance (winter - early spring); winter flounder, Atlantic mackerel and cunner (late spring - early summer); hake, rockling and cunner (late summer - autumn).

4. No lobster larvae were collected in the entrainment samples for 1998.

5. In 1998, an estimated 5.124×10^9 fish eggs and 8.821×10^8 fish larvae were entrained at Pilgrim Station, assuming full flow capacity of all seawater pumps. On an annual basis, eggs were dominated by the labrid-Pleuronectes group and Atlantic mackerel, and larvae by winter flounder and cunner.

6. On several occasions in 1998, "unusually abundant" ichthyoplankton densities were recorded including hake larvae for the most extended time period. This possibly reflects strong annual spawning production for the species involved.

7. The mean annual losses attributable to PNPS entrainment for the adult stage of three abundant species of fish for 1998 were as follows: cunner 1,522,731; Atlantic mackerel 1, 082; winter flounder 5,473-77,428. None of these losses for cunner or Atlantic mackerel were found to be significant in the context of preliminary population or fishery effects, respectively. Comprehensive population impact studies are presently being conducted for winter flounder in the Pilgrim area.

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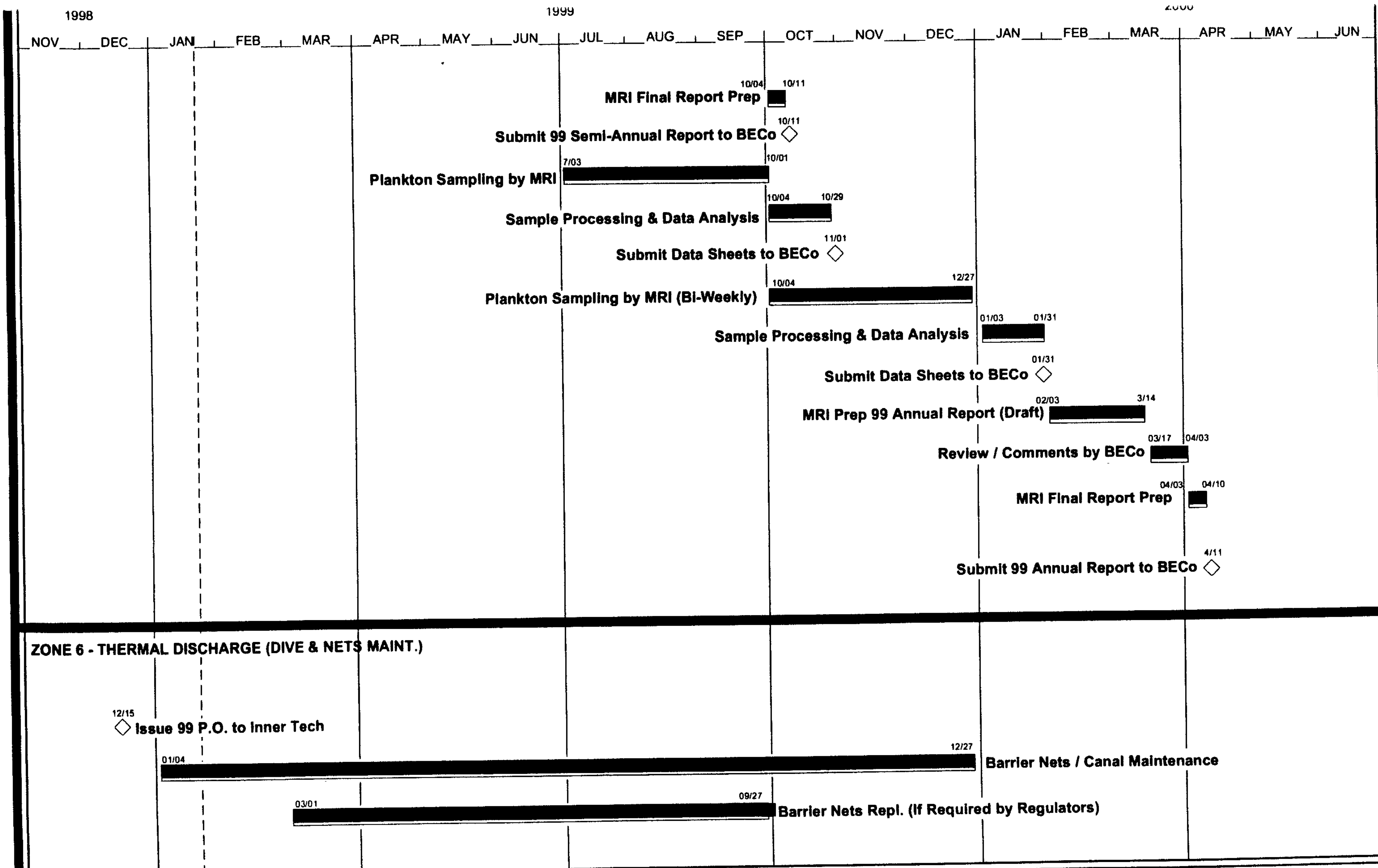
INTRODUCTION

A. Scope and Objective

This is the fifty-third semi-annual report on the status and results of the Environmental Surveillance and Monitoring Program related to the operation of Pilgrim Nuclear Power Station (PNPS). The monitoring programs discussed in this report relate specifically to the Cape Cod Bay ecosystem with particular emphasis on the Rocky Point area. This is the fortieth semi-annual report in accordance with the environmental monitoring and reporting requirements of the PNPS Unit 1 NPDES Permit from the U.S. Environmental Protection Agency (#MA0003557) and Massachusetts Department of Environmental Protection (#359). A multi-year (1969-1977) report incorporating marine fisheries, benthic, plankton/entrainment and impingement studies was submitted to the NRC in July 1978, as required by the PNPS Appendix B Tech. Specs. Programs in these areas have continued under the PNPS NPDES Permit. Amendment #67 (1983) to the PNPS Tech. Specs. deleted Appendix B non-radiological water quality requirements as the NRC felt they were covered in the NPDES Permit.

The objectives of the Environmental Surveillance and Monitoring Program are to determine whether the operation of the PNPS results in measurable effects on the marine ecology and to evaluate the significance of any observed effects. If an effect of significance is detected, Boston Edison Company has committed to take steps to correct or mitigate any adverse situation.

These studies are guided by the Pilgrim Administrative-Technical Committee (PATC), which was chaired by a member of the Mass. Department of Environmental Protection in 1998, and whose membership includes representatives from the University of Massachusetts, the Mass. Department of Environmental Protection, the Mass. Division of Marine Fisheries, the National Marine Fisheries Service (NOAA), the Mass. Office of Coastal Zone Management, the U.S. Environmental Protection Agency, and Boston Edison Company. Copies of the minutes of the Pilgrim Station Administrative-Technical Committee meetings held during this reporting period are included in Section IV.



PNPS 1999 ENVIRONMENTAL PROGRAMS

(NPDES PERMIT #MA 0003557)

3. Plankton Monitoring

Marine Research, Inc. (MRI) of Falmouth, Massachusetts, has been monitoring entrainment in Pilgrim Station cooling water for fish eggs and larvae, and lobster larvae (from 1973-1975 phytoplankton and zooplankton were also studied). Information generated through this monitoring has been utilized to make periodic modifications in the sampling program to more efficiently address the question of the effects of entrainment. These modifications have been developed by the contractor, and reviewed and approved by the PATC on the basis of the program results. Plankton monitoring in 1998 emphasized consideration of ichthyoplankton entrainment and selected species adult equivalency analyses. Results of the ichthyoplankton entrainment monitoring and impact analysis for this reporting period are discussed in Section IIIC.

4. Impingement Monitoring

The Pilgrim Station impingement monitoring and survival program speciates, quantifies, and determines viability of the organisms carried onto the four intake traveling screens. Marine Research, Inc. has been conducting impingement sampling with results being reported on by Boston Edison Company in 1998.

A new screen wash sluiceway system was installed at Pilgrim in 1979. This new sluiceway system was required by the U.S. Environmental Protection Agency and the Mass. Division of Water Pollution Control as a part of NPDES Permit #MA0003557. Special fish survival studies conducted from 1980-1983 to determine its effectiveness in protecting marine life were terminated in 1984, and a final report on them appears in Marine Ecology Semi-Annual Report #23.

Results of the impingement monitoring and survival program, as well as impact analysis, for this reporting period are discussed in Section IIID.

D. Station Operation History

PNPS was in a high operating stage during most of this reporting period with a 1998 capacity factor (MDC) of 97.1%. Cumulative capacity factor from 1973-1998 is 56.0%. Capacity factors for the past 15 years are summarized in Table 1.

E. 1999 Environmental Programs

A planning schedule bar chart for 1999 environmental monitoring programs related to the operation of Pilgrim Station, showing task activities and milestones from December 1998 - June 2000, is included after Table 1.

Table 1. PILGRIM NUCLEAR POWER STATION UNIT 1 CAPACITY FACTOR USING MDC NET% (Roughly approximates thermal loading to the environment: 100%=32 Degrees F Δ T)

Month	1998	1997	1996	1995 *	1994 *	1993	1992	1991	1990	1989	1988 *	1987 *	1986	1985	1984 *
January	98.4	92.5	92.1	99.1	98.8	99.0	96.6	95.4	99.4	0.0	0.0	0.0	79.5	54.0	0.0
February	99.5	42.1	99.4	96.3	72.5	96.7	99.4	88.9	97.4	0.0	0.0	0.0	97.7	59.3	0.0
March	99.5	0.0	99.3	74.4	79.5	83.2	80.4	84.6	30.0	10.7	0.0	0.0	26.9	81.8	0.0
April	97.0	21.4	75.9	0.0	63.3	6.4	53.5	92.7	5.4	10.5	0.0	0.0	11.9	90.8	0.0
May	92.5	97.4	98.2	0.0	94.5	0.4	97.8	0.0	77.9	4.6	0.0	0.0	0.0	94.3	0.0
June	99.4	98.1	94.3	65.1	97.2	77.5	97.8	0.0	96.3	16.4	0.0	0.0	0.0	85.0	0.0
July	95.5	95.5	95.3	95.7	97.6	80.3	97.4	0.0	55.1	28.6	0.0	0.0	0.0	96.9	0.0
August	93.0	96.4	92.3	97.7	88.2	86.9	97.4	28.5	94.5	50.8	0.0	0.0	0.0	96.5	0.0
September	93.3	97.4	51.4	96.7	0.0	84.8	94.1	96.4	21.6	52.5	0.0	0.0	0.0	71.4	0.0
October	99.4	98.7	94.0	94.3	0.0	98.0	72.8	94.2	98.7	30.1	0.0	0.0	0.0	95.4	0.0
November	99.6	69.5	94.9	99.5	0.2	80.0	13.7	23.7	96.8	66.0	0.0	0.0	0.0	88.1	0.0
December	98.2	68.8	97.7	98.8	87.7	94.8	65.2	98.1	94.5	77.1	0.0	0.0	0.0	99.1	0.7
ANNUAL%	97.1	73.4	90.5	76.4	65.2	74.0	80.6	58.4	72.3	28.9	0.0	0.0	17.5	84.4	0.1

CUMULATIVE CAPACITY FACTOR (1973-1998) -= 56.0%

________________ = outages >2 months

*= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 27 MARCH - 13 AUGUST, 1984
= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 18 FEBRUARY - 8 SEPTEMBER, 1987
= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 14 APRIL - 5 JUNE, 1988
= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 9 OCTOBER - 16 NOVEMBER, 1994
= NO CIRCULATING SEAWATER PUMPS IN OPERATION FROM 30 MARCH - 15 MAY, 1995

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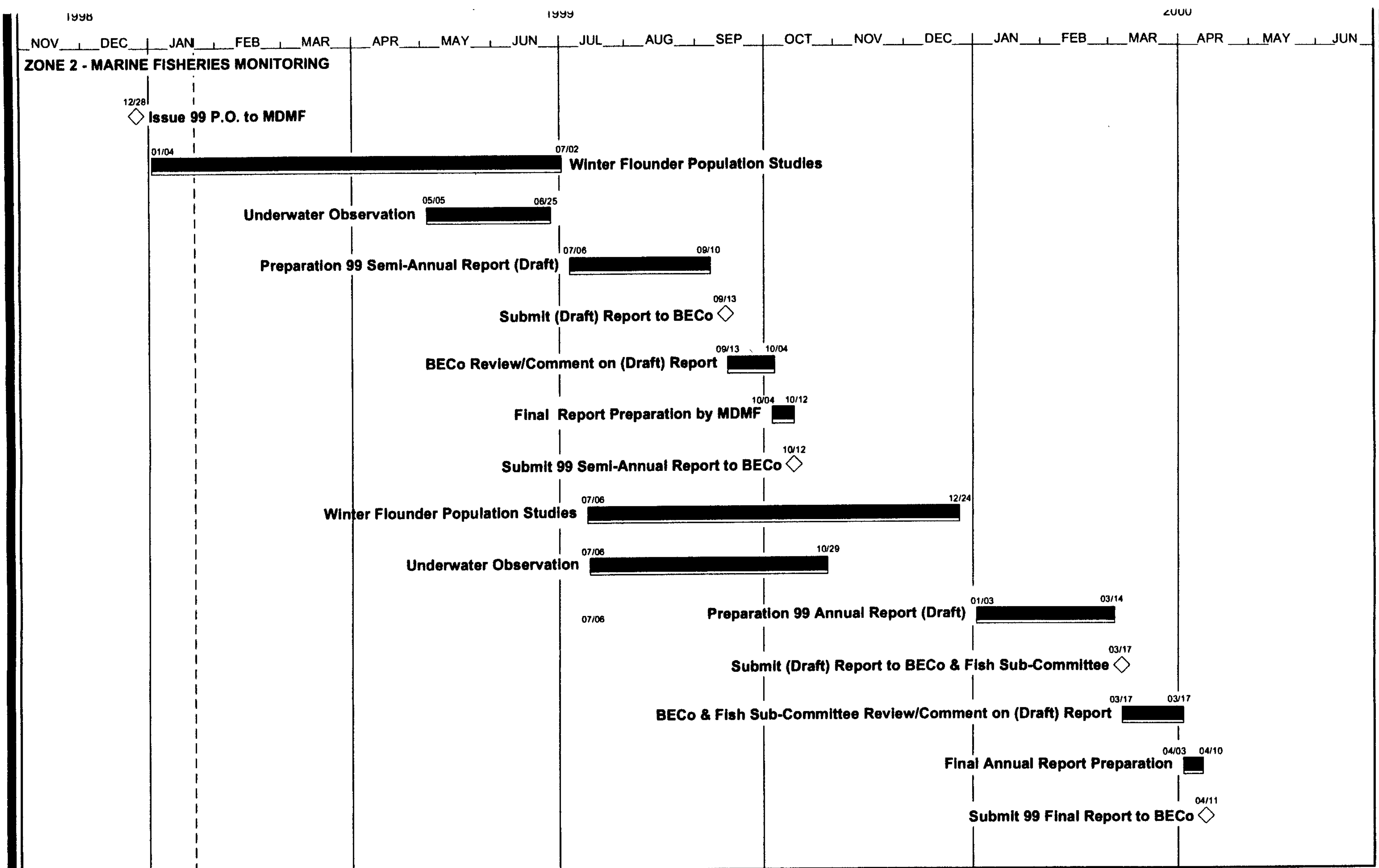
ZONE 1 - PATC

Timeline: 1998 (NOV, DEC) – 1999 (JAN–DEC) – 2000 (JAN–JUN)

Task	Start	Finish
99 Monitoring Programs (NPDES) to EPA NRC MDEP	01/04	
PATC (Full Committee)	06/17	
Review Results of 98 Programs	06/17	
FISHERIES (Sub-Committee)	07/19	
Recommend for FISHERIES 2000 Programs	07/19	08/13
BENTHIC (Sub -Committee)	07/22	
Recommend for BENTHIC 2000 Programs	07/22	08/13
PATC (Full Committee)	10/04	
Recommend for 2000 Monitoring (NPDES) Programs	10/04	
BECo Meeting with EPA MDEP (Potential)	10/18	
BECo Preparation (NPDES) 2000 Monitoring Programs	11/01	11/29
BECo Approve (NPDES) 2000 Monitoring Programs	12/02	12/13
Submit 2000 Programs (NPDES) to EPA NRC MDEP	01/03	
Initiate 2000 Monitoring Programs	01/03	
PATC (Full Committee)	06/19	
Review Results of 99 Programs	06/19	

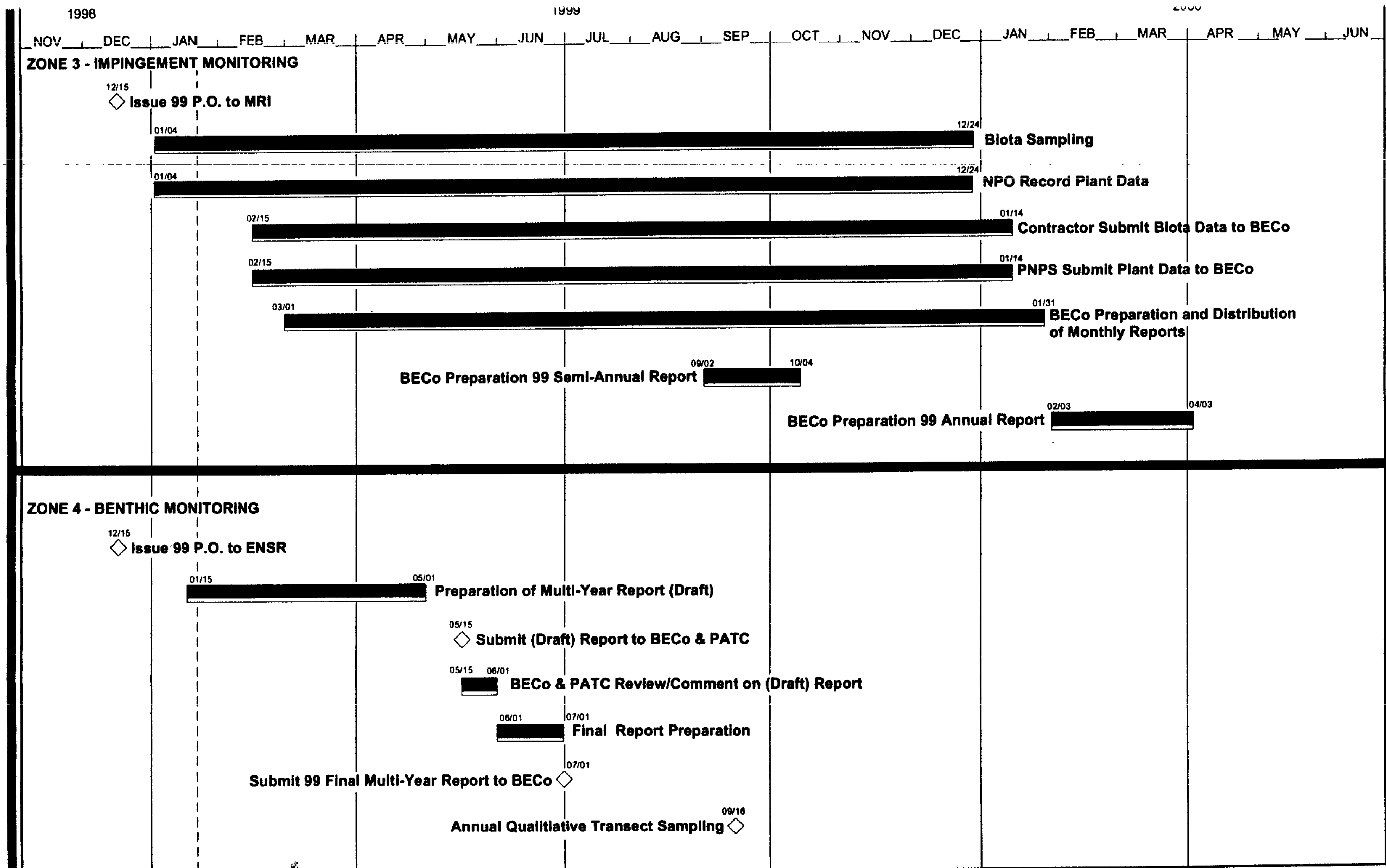
PNPS 1999 ENVIRONMENTAL PROGRAMS

(NPDES PERMIT #MA 0003557)



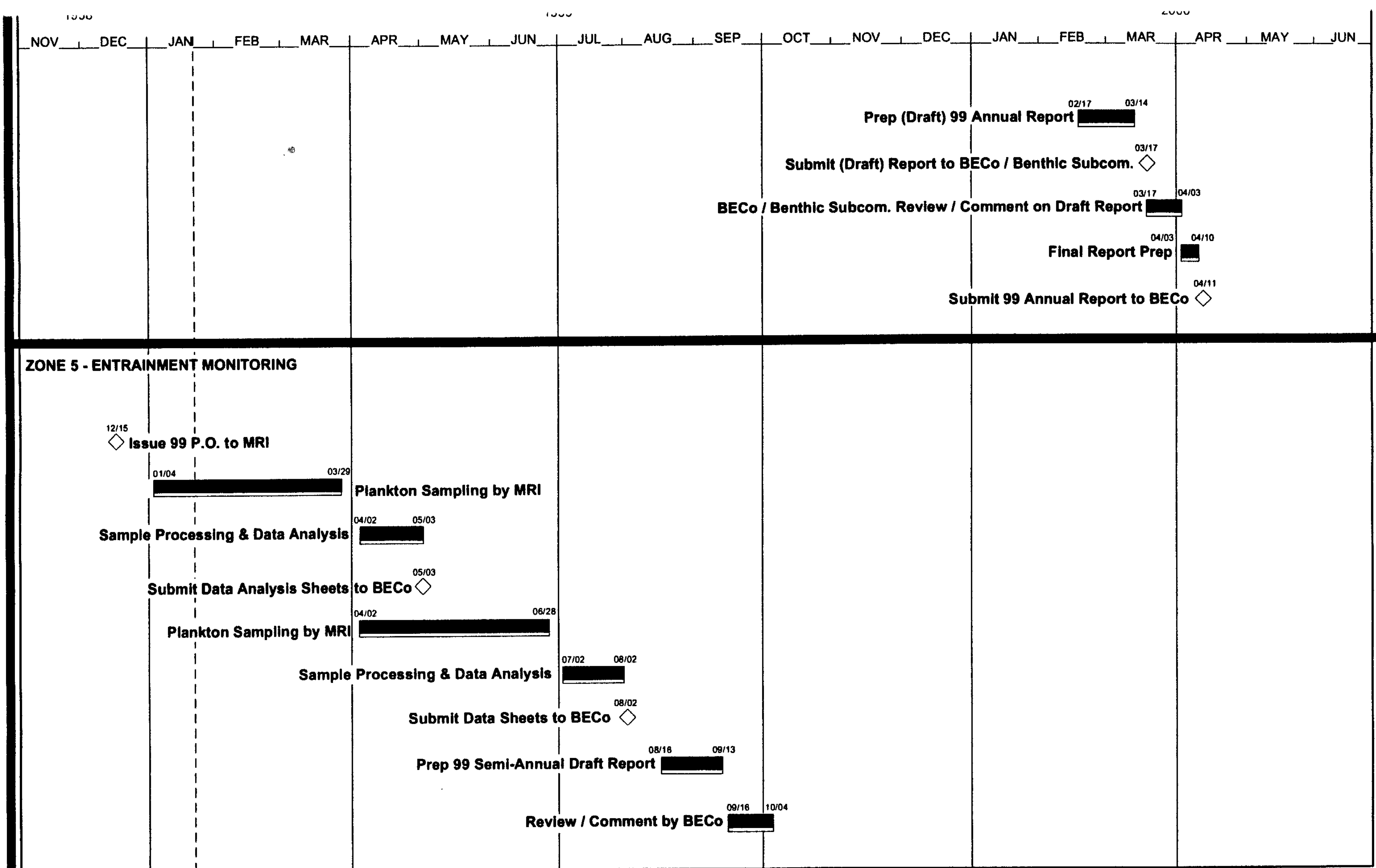
PNPS 1999 ENVIRONMENTAL PROGRAMS

(NPDES PERMIT #MA 0003557)



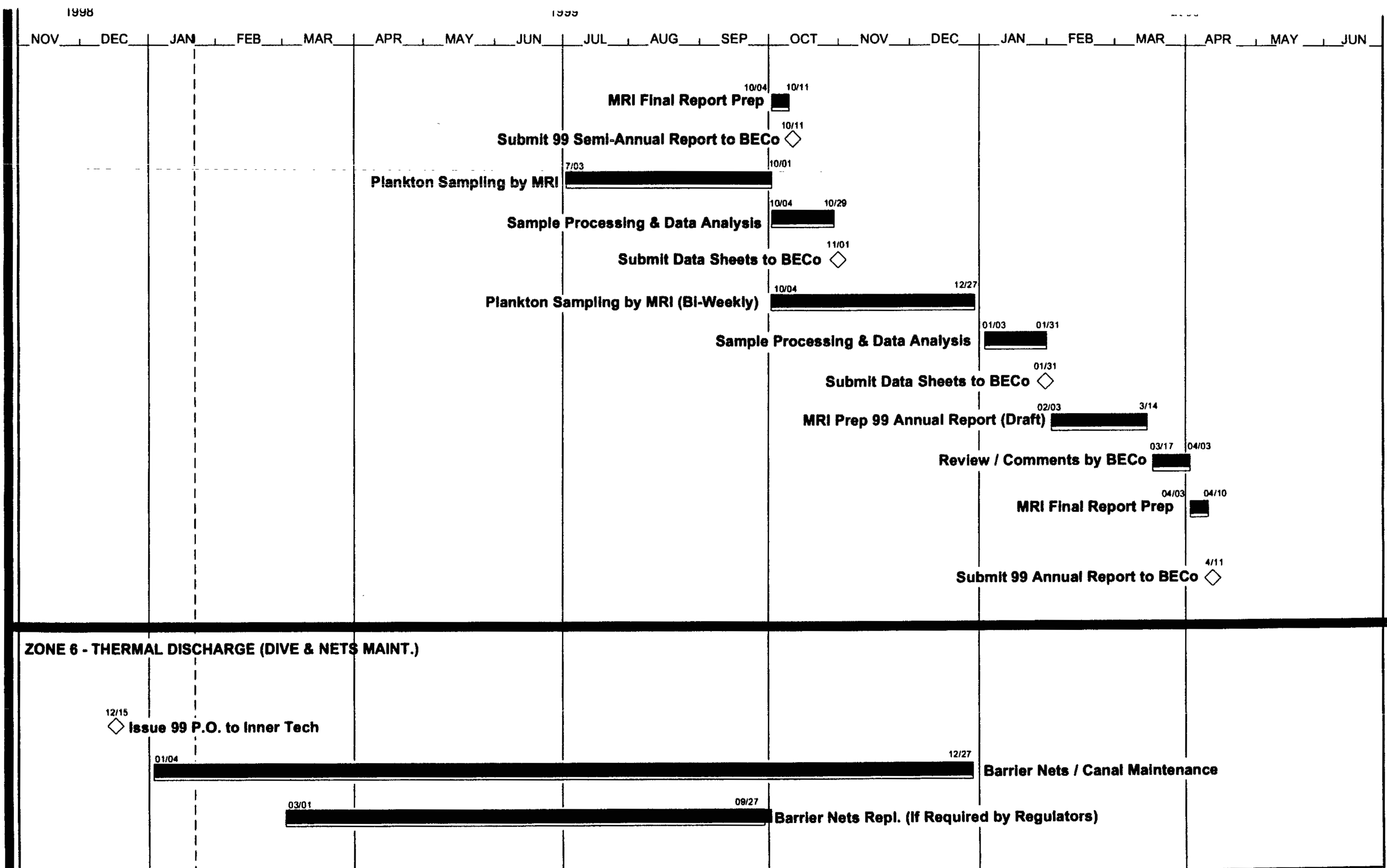
PNPS 1999 ENVIRONMENTAL PROGRAMS

(NPDES PERMIT #MA 0003557)



PNPS 1999 ENVIRONMENTAL PROGRAMS

(NPDES PERMIT #MA 0003557)



PNPS 1999 ENVIRONMENTAL PROGRAMS

(NPDES PERMIT #MA 0003557)

NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN

ZONE 7 - REPORT MONITORING PROGRAMS

Task	Start	Finish
NPDES Permit 99 Semi-Annual Report Prep.	09/02	10/15
Printing Final Semi-Annual Report	10/15	10/22
BECo Review / Comment / Approval of Semi-Annual Report	10/25	10/29
Submit 99 Semi-Annual Report to EPA / MDEP / NRC	11/01	
NPDES 99 Annual Report Prep	03/03	04/17
Printing Final Annual Report	04/17	04/22
BECo Review / Comment / Approval of Annual Report	04/22	04/30
Submit 99 Annual Report to EPA / MDEP / NRC	05/02	

PNPS 1999 ENVIRONMENTAL PROGRAMS

(NPDES PERMIT #MA 0003557)

ANNUAL REPORT ON ASSESSMENT AND MITIGATION OF IMPACT OF THE PILGRIM NUCLEAR POWER STATION ON FINFISH POPULATIONS IN WESTERN CAPE COD BAY

Project Report No. 66 (January to December 1998)

By
Robert Lawton, Brian Kelly,
John Boardman, and Vincent Malkoski

April 1999
Massachusetts Department of Fisheries,
Wildlife, and Environmental Law Enforcement
Division of Marine Fisheries
100 Cambridge Street
Boston, Massachusetts 02202

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VII. LITERATURE CITED

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I. EXECUTIVE SUMMARY

The following are the 1998 highlights of study findings for selected species. Additional information can be found in the Conclusions section of this report.

Rainbow Smelt

- Rainbow smelt (*Osmerus mordax)* impingements of different magnitudes have occurred at Pilgrim Nuclear Power Station over the years of station operation. The smelt is considered an "important representative species" due to its abundance and recreational importance in the Plymouth, Kingston, Duxbury Bay (PKDB) area. Boston Edison Co. has funded the Massachusetts Division of Marine Fisheries (MDMF) in our remediation efforts to compensate for these impingement mortalities. Our overall goal has been to increase the number of adult smelt in the local population and thus offset power plant impact. Efforts have included augmenting natural egg production and enhancing spawning habitat to optimize egg hatchout.
- During the springs of 1994 and 1995, smelt eggs were obtained from two genetically isolated, wild, anadromous Massachusetts populations: one from the Weweantic River, Wareham and the other from Back River, Weymouth and transplanted into the Jones River, a tributary to PKDB. Eggs were collected using our portable sphagnum moss-filled incubation trays, which provide ideal habitat for egg development and survival. We stocked ca. 1.8 million smelt eggs into the Jones River. Larvae were expected to imprint on the waters of PKDB and return to the Jones River and its other tributaries to spawn when sexually mature. The stocking portion of our project has been discontinued due to reduced egg production in our two "source" streams, with no other accessible supply of eggs to be found.
- To address spawning habitat enhancement, we again used our egg collecting trays. Each spawning season from 1994 to 1998, a number of trays were placed in the Jones River on the smelt spawning grounds, where spawning activity has consistently been greatest in past years. The trays were emplaced in the river before smelt spawning commenced and were removed after egg hatching was completed.

Unwanted fouling material was regularly removed from the trays to improve water circulation over the eggs.

- We feel that improving water quality in the Jones River and other tributaries to PKDB is an important goal for the future. The MDMF will continue to place trays into the river during the smelt spawning period to continue husbandry practices. We also will monitor spawning activity and egg production densities, while conducting periodic checks to make sure the river is free of obstacles, such as fallen trees, that could hinder fish passage.

Winter Flounder

- The PKDB and surrounding coastal waters are important spawning areas for winter flounder (*Pseudopleuronectes americanus*). In the PNPS study area, winter flounder exhibit fairly high fidelity to natal spawning grounds. In general, they also undertake local seasonal movements which appear to be temperature driven.
- In 1998, an estimated 88.8 million winter flounder larvae were entrained at PNPS, which equates to an ultimate equivalent loss of 77,428 adults from the local population. This is by far the highest flounder larval entrainment recorded at the plant. Entrainment was markedly up from last year, when 55.4 million flounder larvae were entrained which equated to the equivalent loss of 47,087 adult flounder.
- An estimated 1,493 winter flounder - mostly age 0 and age 1 - were impinged at PNPS in 1998.
- Only seven winter flounder reportedly were caught by anglers at the PNPS Shorefront in 1998.
- In 1998, we tagged 7,494 winter flounder with Petersen disc tags (light green in color), bringing the study total to 22,476 marked fish. As of the end of 1998, 896 of the flounder tagged had been recaptured for a recapture rate of 4.0%. Tag returns by area for winter flounder recovered during the non-spawning period (June-February) from 1993-1997 and (June-December) of 1998 suggest that a

large proportion of the flounder do not move far afield from the overall tagging area (Areas 1-3) after the spawning season (March-May). Tag returns by area recovered during the spawning period from 1993-1998 were primarily from Area 2 (72%). Our tag data reveal that most movements of winter flounder in the Plymouth area are restricted to relatively short distances, and there appears to be a fairly high fidelity in the local population.

- Density extrapolation, using the Area/Density Method, provides an estimate of the adult winter flounder population size (absolute abundance) for the study area of fish ≥ 280 mm total length (TL), i.e., age 3 and older adults,.which was 264,812 for 1998. This is substantially less than 1997, when adults in the study area were estimated at 321,831. The data suggest that total annual mortality was high.
- Population estimates of winter flounder for the study area (fish ≥ 280 mm TL), obtained from a number of mark-recapture models, were considerably lower, being in the 100,00 range.
- The recapture rate of tagged flounder is low, which affects the predictive value of mark/recapture population model estimators for abundance, while the variability in area-swept estimates is somewhat problematic. The equivalent adult loss because of entrainment mortality in 1998 is estimated to represent approximately 29% of the number of adults in the local population, estimated by Area /Density methodology.

Other Species

- Atlantic silverside (*Menidia menidia*) is typically impinged annually in high numbers (several thousand individuals), but no compensatory action has been taken because the species is short-lived and prolific.
- Alewife (*Alosa pseudoharengus*) impingement should continue to be monitored, as a large impingement incident of 13,100 juvenile alewives did occur in 1995.

- Striped bass (*Morone saxatilis*), bluefish (*Pomatomus saltatrix*), winter flounder , and tautog (*Tautoga onitis*) were the species reported in the recreational catch at the PNPS Shorefront in 1998.
- Striped bass and tautog dominated the SCUBA finfish sightings off PNPS, with small aggregations of cunner (*Tautogalabrus adspersus)* also observed.
- Data from the sportfish and underwater visual surveys reveal that some finfish species are attracted to the thermal discharge at PNPS. This places them at risk from temperature aberrations, chemical releases, and potential gas bubble disease problems. As such, direct visual monitoring in the discharge area is helpful.

II. INTRODUCTION

The Massachusetts Division of Marine Fisheries (MDMF) power plant team has conducted field investigations to assess environmental effects of the operation of Pilgrim Nuclear Power Station (PNPS). In some instances, mitigative or remedial measures have been instituted to offset adverse impacts. This work was funded by Boston Edison Company (BECo) under Purchase Order No. LSP009438 in 1998.

In 1998, we focused on winter flounder (*Pseudopleuronectes americanus*) and rainbow smelt (*Osmerus mordax*), employing a suite of gear types, equipment, and techniques to sample and, when appropriate, to undertake restorative measures. Descriptive statistics are summarized in tables or displayed in figures., and statistical procedures also are used.

From extensive field studies off PNPS, it is evident that mechanical aspects of this station's operations, i.e., entrainment of fish eggs and larvae, and to a lesser extent, impingement of juvenile and adult fish, pose greater environmental threats than does the release of waste heat into the receiving waters.

The two finfish species of particular concern at present in the PNPS area are winter flounder and rainbow smelt (Table 1). The PNPS area serves as winter flounder spawning, nursery, and feeding grounds. This flatfish is a highly valued commercial and recreational species. Winter flounder larvae have been entrained in relatively high numbers. Rainbow smelt is valued as a recreational species in the nearby Plymouth, Kingston, Duxbury Bay (PKDB) estuary. Several incidents of relatively high smelt impingement have occurred at PNPS over the years.

Our objectives in 1998 were: (1) for winter flounder, to determine discreteness of the local population and estimate absolute abundance of the adult segment of the population; and (2) for rainbow smelt, to enhance the quality of spawning habitat in the nearby Jones River, a tributary to PKDB, where most of the local smelt population originates, by collecting their eggs on ideal substrate to improve survival.

Table 1. Important indicator species off the Pilgrim Nuclear Power Station.*

Species	Background History	Basis for Selection as an Indicator Species	Possible Sources of Impact	Most Significant Source of Impact (Based on Results to Date)
Rainbow Smelt	RIS	r, s	I, T/C	Impingement - large incidents in December of '78, '93, '94
Winter Flounder	RIS	d, r, c, s	I, E, T/C	Entrainment - large number of larvae collected (April-May)

RIS - representative important species selected in the original 316 (a and b) Demonstration Document and Supplement to assess Pilgrim Station impact (Stone and Webster 1975 and 1977).

d - a dominant species in the Pilgrim area.
r - a local resident
c - commercial importance
s - recreational importance

I - impingement
E - entrainment
T/C - discharge current effects: thermal/current

* Note: Indicator species selection rationale: these two species were selected because they have shown the most potential for impact off Pilgrim Station and may be indicative of power plant induced stresses to other marine fish species.

This annual report includes a description of sampling design and methodology, together with findings, conclusions, and any recommendations. Progress achieved in assessment surveys and ongoing restorative projects was highlighted for these indicator species in the PNPS area.

In 1999, our efforts will again focus on winter flounder and rainbow smelt.

III. METHODS AND MATERIALS

The study area for 1998 is bounded in Figure 1.

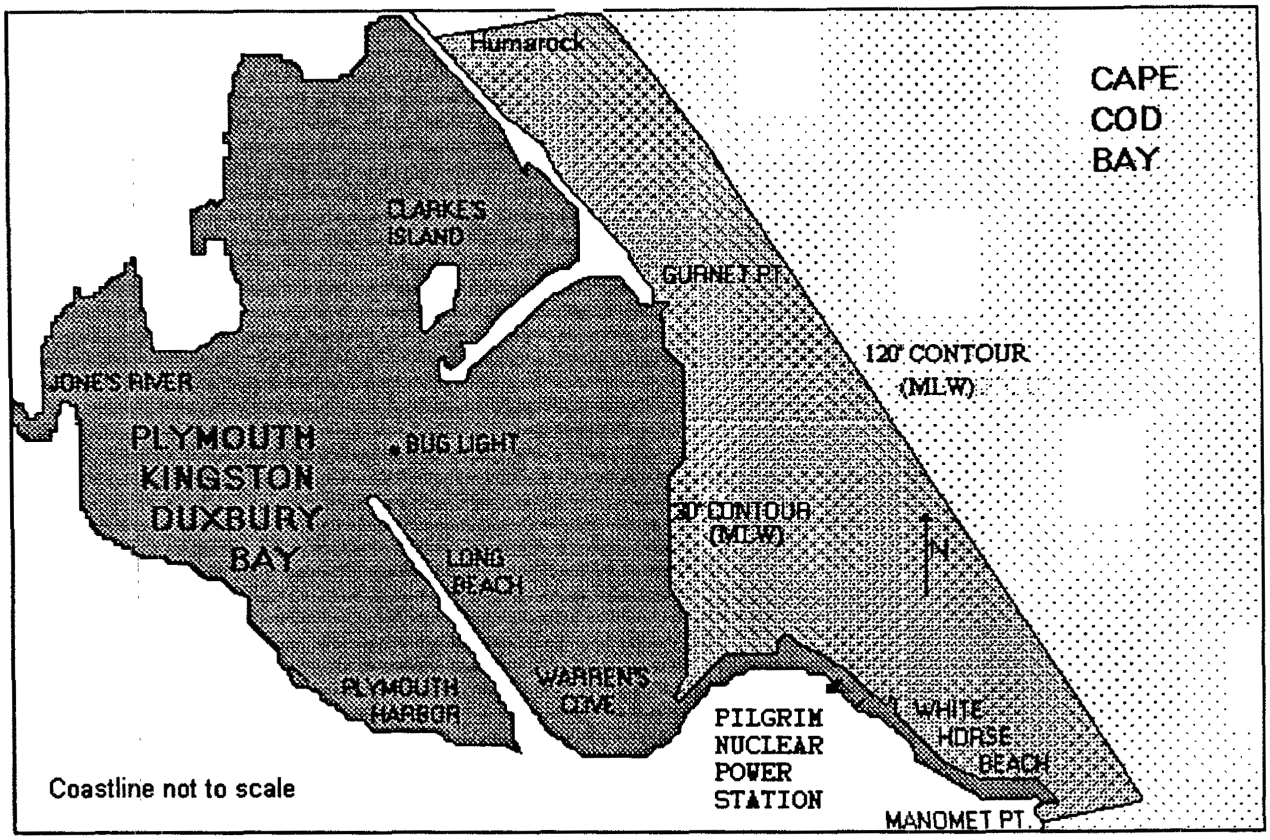

Figure 1. PNPS investigative area for rainbow smelt and winter flounder, January-December, 1998. Depth strata are shaded differently.

Rainbow Smelt

Eggs and Larvae. We allowed rainbow smelt to spawn naturally over egg collecting units placed in the Jones River. Each collection unit (35.6 x 45.7 cm) was a weighted wooden frame, enclosed with chicken wire, and filled with unprocessed sphagnum moss which served as substrate for egg deposition (Figure 2). We deployed the egg trays into selected riffle areas of the upper Jones River smelt spawning ground. We inspected, serviced, and monitored these units every few days for egg deposition, development, and survival. Fouling macro-algae were removed and discarded downstream of the spawning area. We endeavored to minimize egg disturbance and mortality on the river bed and on our trays during this process.

Following egg hatchout, larvae are carried downstream and into the waters of PKDB as they develop. When adults, they should home back to this estuary, ascending the Jones River and possibly other tributaries in this complex to spawn.

<u>Juveniles.</u> Three unusually large rainbow smelt impingement incidents have occurred at PNPS, in December, of 1978, '93, and '94. The majority of smelt impinged were age-0 fish (juveniles). Impingement sampling data are collected by Marine Research, Inc. (see Impingement section, this report).

<u>Adults.</u> Adult rainbow smelt (Figure 2) also are impinged at PNPS (see Impingement section).

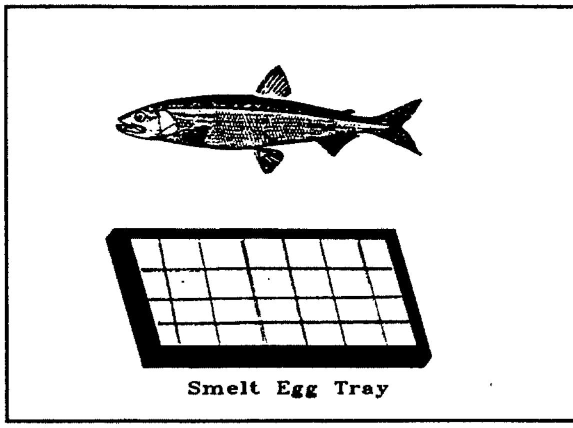

Figure 2. A sphagnum moss filled collecting unit of the type used to collect and incubate smelt eggs (smelt shown above) in the Jones River.

<u>Winter Flounder</u>

<u>Eggs and larvae</u>. Data on these two life stages (primarily larvae) are collected by Marine Research, Inc. in their entrainment sampling program at PNPS (see Entrainment section, this report).

<u>Juveniles</u>. Juvenile winter flounder are impinged at PNPS, with monitoring data also collected by Marine Research, Inc. (see Impingement section, this report).

<u>Adults</u>. Our objectives have been to determine the discreteness (fidelity) of the local winter flounder population and to estimate absolute abundance. This information is being used to assess impact of flounder entrainment and impingement at PNPS.

During the winter flounder spawning season north of Cape Cod (March-May), some flounder may move in and/or out of PKDB (Figure 1), with evidence of spawning both inside and outside this estuary. Flounder may aggregate in pre-spawning staging areas out in deeper water, with some moving into the estuary at night on a flood tide to spawn in the shallows.

We contracted two commercial fishing vessels in 1998 to sample winter flounder: one, the F/V *Frances Elizabeth*, for tagging and recapture purposes, and the other, the F/V *Alosa*, to estimate flounder density and to sample outside the tagging area for tag recaptures. The tagging study area was the same as last year and included the waters from Humarock, Marshfield southeastward to the Mary Ann buoy, Manomet, from nearshore (9.2 m MLW) out to the 36.6 m (MLW) depth contour (Figure 1).

Trawl gear on the F/V *Frances Elizabeth* was unchanged from 1997, namely, a Yankee otter trawl (21.9-m sweep and 15.8-m headrope, which had a 15.2-cm stretch mesh and a 7.6-cm mesh liner); it was fished with 12.8-m legs and 78.6-m ground cables. The trawl doors (#5 Bison doors) were of steel (1.5 m x 0.9 m and 181 kg each). Warp length varied with depth of water fished, ranging from 73.8 to 92.3 m. Measurements made while fishing indicated that the door and net spread were approximately the same as in 1997. Trawl gear on the F/V *Alosa* consisted of a Yankee otter trawl (18.3-m sweep and 12.2-m headrope, which had a 15.2-cm stretch mesh and a 4.5-cm mesh liner); it was fished with 12.8-m legs and 73.2-m ground cables. The trawl doors (#63 Thiboron doors) were of steel (1.5 m x 0.9 m and 181 kg each).

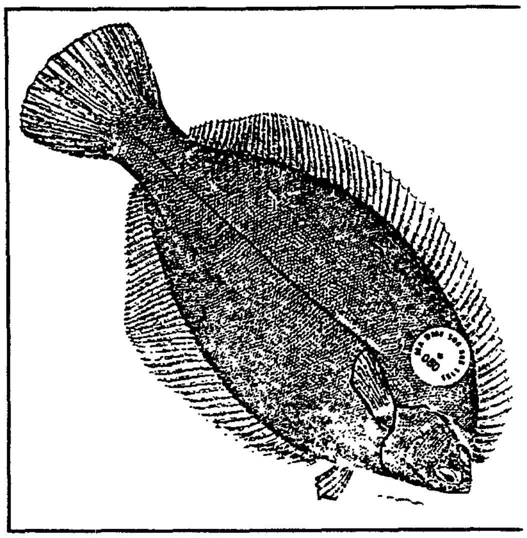

Figure 3. Winter flounder with Petersen disc tag attached (tag not to scale).

Winter flounder were enumerated, measured (TL), sexed, and assessed for maturity and reproductive state before being released near capture sites. In addition, aboard the F/V *Frances Elizabeth,* flounder ≥ 280 mm TL were marked with green Petersen disc tags (Figure 3). Within the tagging area, fish have been marked at locations selected on the basis of known local flounder concentrations (staging areas) primarily during the spring flounder spawning season (March-May) from 1993-1998. Data also were collected on net geometry and the trawl distance of each tow. Tow duration and distance on each boat averaged 30 minutes and 1.2 km, respectively. We generated independent estimates of population size via mark and recapture and by an area-swept approach (density extrapolation).

We estimated winter flounder population size (instantaneous absolute abundance) for 1998 using an area/density approach, based on density extrapolation over the total study area from five days of trawl area-swept sampling aboard the F/V *Alosa* within the tagging area. As trawl gear efficiency in our sampling was unknown, we assumed it to be 50%. To estimate density, the number of winter flounder by tow (data transformed via ln(x+1)) was divided by the area of bottom covered. Tow length was determined, and tow width was estimated from the trawl doors' spread on the bottom. Door spread is used as a measure of width because of the "herding" action caused by the sediment cloud generated by the doors and legs while towing. Catch per unit area was calculated for individual tows. The estimates computed for adult winter flounder ($\geq$ 280 mm TL) and for all sizes pooled were doubled to reflect the assumed catch efficiency. Density estimates (number per m^2) were multiplied by the total bottom acreage in the study area to obtain estimates of absolute abundance. Bottom area was determined using a dot grid and navigational charts. Acreage was converted to square meters.

We also estimated numbers of winter flounder $\geq$280 mm TL using several mark-recapture models utilizing sampling data collected aboard the F/V *Frances Elizabeth*:

Closed population models -

single episode of tagging and one of recapturing = Petersen method;

multiple markings = Schnabel method, Schumacher and Eschmeyer method, Mark method, and Capture method;

Open population model -

multiple census = Jolly-Seber method.

For modeling estimates of absolute population abundance in 1998, except for the Petersen method, we used our 1998 green tag recovery data for winter flounder at large $\geq$2 days and recaptured during our tagging period (30 March to 5 May 1998) for a total of 24 sampling days. For the Petersen method, we grouped the green tag recapture data into two periods for analysis - the first 24 sampling days (i.e., the tagging period) versus the last 3 sampling events (6 May to 8 May).

Other Fish Species

Eggs and Larvae. Egg and larval information for other finfish species entrained at Pilgrim Station were obtained by Marine Research, Inc. (see Entrainment section, this report).

Juveniles. We also collected data on juveniles of several finfish species using SCUBA diving and fish potting. Impingement data were obtained from Marine Research, Inc. and BECo.

Adults. (Same as for juveniles)

IV. RESULTS AND DISCUSSION

A. PHYSICAL FACTORS

1. Power Output-Thermal Capacity

Pilgrim Nuclear Power Station's capacity factor (MDC net percent) is an index of operational status that approximates thermal loading into the nearshore receiving waters of western Cape Cod Bay. This factor is relevant when assessing long-term thermal impact on marine organisms. By permit regulation, PNPS is allowed a maximum discharge temperature of 38.9°C and an effluent Δ T of 18°C above ambient. For the 26-year history of plant operations, the long-term mean MDC at PNPS is 56.0%, with annual averages ranging from 0.0% (outage years) to 97.1% in 1998 (Figure 4). The 1998 power output was an all time high for PNPS; for most months, the plant operated near 100% capacity. Annual thermal capacity increased nearly 24.0% from 1997.

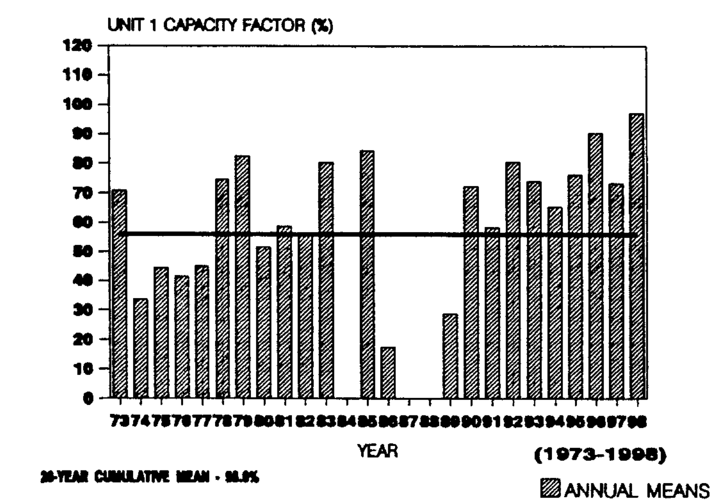

Figure 4. Annual means and 26-year cumulative Mean Capacity Factor (MDC Net %) for Pilgrim Nuclear Power Station, 1973 through 1998.

2. Pump Operations

Once-through, open-cycle cooling at PNPS induces a localized water current flow just off the plant. Two circulating seawater pumps [586.7 kl/min each (155,000 gals/min)] withdraw water from an artificially created intake embayment that is bounded by breakwaters and rip-rap. The cooling water circulates through the plant condenser tubes before being discharged back into the waters of western Cape Cod Bay with waste heat. At ebb tide, effluent velocities can exceed 2.1 m/sec (7 ft/sec) at the egress of the discharge canal. This results in scouring of the benthos and concomitant erosion of substrate along the bottom path of the discharge plume.

Throughout the operational history of PNPS, there have been station outages, when one or both circulating seawater pumps were not operated (Figure 5). Such periods have occurred aperiodically and generally have been short-lived; however, extensive outages occurred in 1984 and from 1986-1988 (see Figure 4). During 1998, both circulating pumps were continuously operated throughout the year. The high operational status at PNPS resulted in a maximum withdrawal of cooling water for the two circulating water pumps. This, in turn, greatly enhanced the potential for entrainment impact at the plant this year (1998).

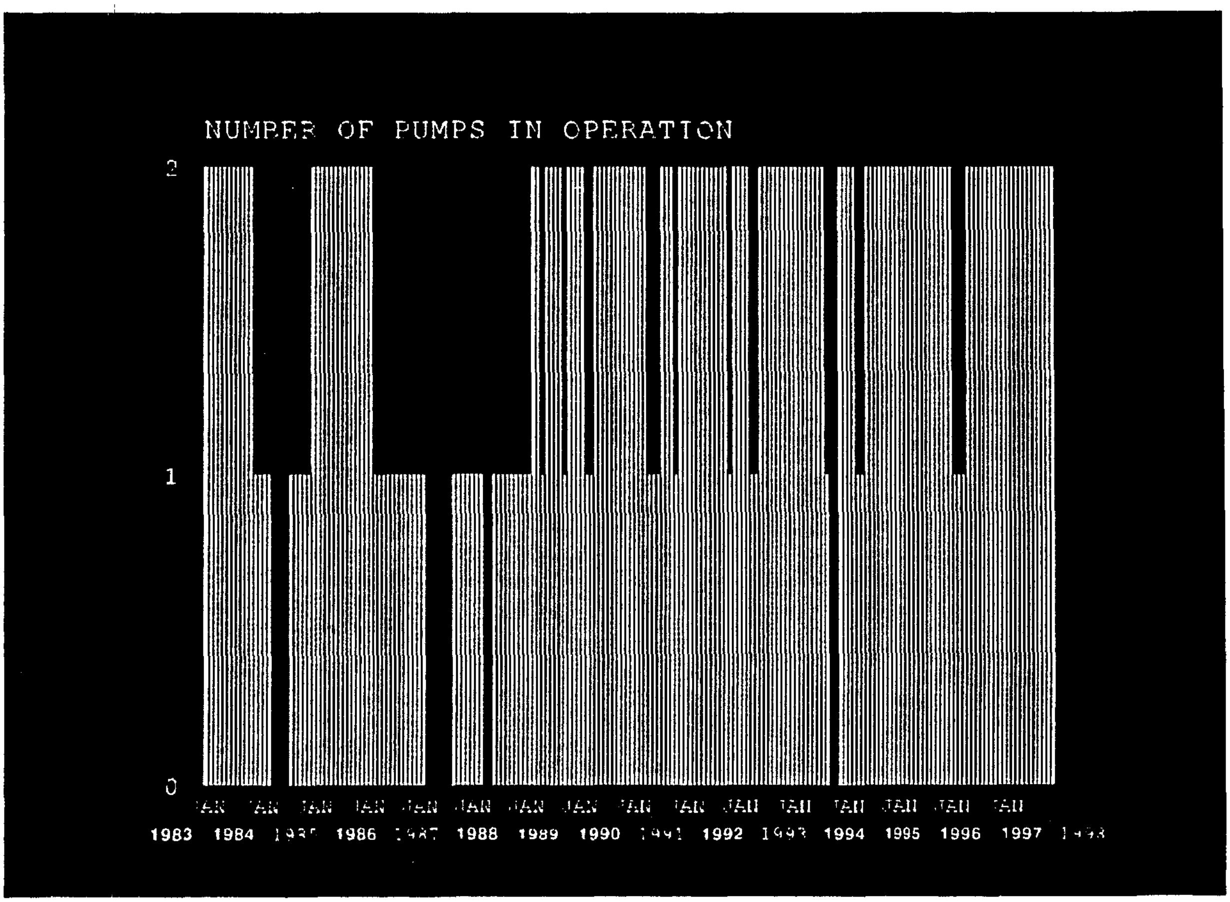

Figure 5. Operational history of the two circulating seawater pumps at Pilgrim Station by month for the years, 1983 through 1998.

B. FINFISH SPECIES OF IMPORTANCE

1. **Rainbow smelt**

Background

The goal of our 1998 rainbow smelt project was to enhance the quantity of quality smelt spawning habitat in the Jones River, a tributary to PKDB. We placed 69 egg collecting trays in the upper smelt spawning area of the Jones River for the period 24 March through 20 May, 1998. The trays collected the naturally spawned, demersal, adhesive smelt eggs, providing an ideal habitat for egg protection and development. The sphagnum moss filling the trays provides a three dimensional depositional surface for the eggs, and represents a micro-environment that offers protection for the developing embryos, reducing ‘egg turnover’ loss. Water can flow through the moss, carrying away metabolic wastes and providing a continuous supply of oxygen to the eggs.

The rainbow smelt spawning ground in the Jones River is comprised largely of hard substrate (gravel, sand, and cobble). Natural aquatic vegetation which provides ideal substrate for egg development covers only a small portion of the spawning ground. Sutter (1980) reported smelt egg survival to hatching was about 10% on vegetation but only 1% on hard surfaces. Trays with sphagnum have consistently collected higher egg sets than natural hard abiotic bottom.

Eggs and Larvae

The 1998 rainbow smelt egg set in the Jones River was the best in over a decade. Areas containing more than 50 eggs per square inch were considered to have heavy sets, while 20 to 50 per square inch were considered moderate sets, and < 20 eggs per square inch were light sets. The majority of available spawning habitat in Zone A and upper third of Zone B was utilized for egg

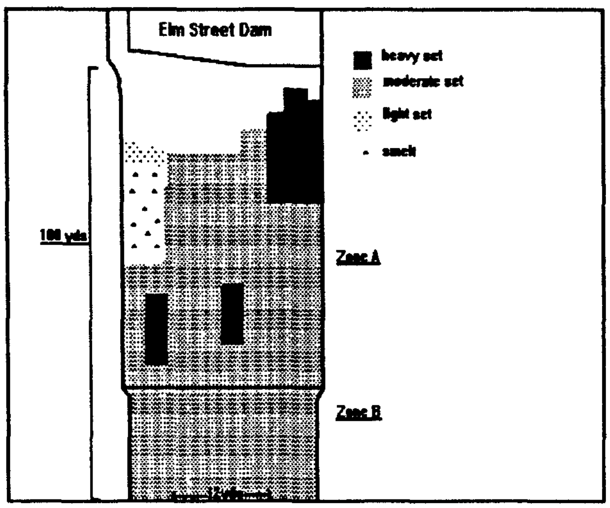

Figure 6. Smelt egg density within Zones A&B of the Jones River habitat enhancement area 1998.

deposition (Figure 6). This section of the river generally was covered by moderate to heavy egg sets. Egg patches of varying densities also could be found throughout the lower two thirds of Zone B and even down to the Route 6A bridge. Most of our egg collecting trays in Zone A were covered with a single layer of eggs. With no major storms occurring, conditions in the Jones River were favorable for successful spawning. The river was free of obstructions, and a good flow existed with many riffle areas observed, which dispersed the eggs and prevented their aggregation in one area. The long filamentous macro-algae, which likely reduce water flow to the developing eggs and have been a problem in years past, were not prevalent this year.

Juveniles

For the last six years (1993-1998), rainbow smelt impingement at PNPS was estimated to total 25,697 fish. A representative sample of impinged fish was measured each year. After comparing lengths of these fish to the mean length at age for smelt from an earlier study of ours in the Jones River, we determined that the majority of impinged fish were juveniles (ages 0+ and 1+ fish). Since smelt spawning runs in the Jones River generally have been depressed for many years, with the exception of 1998, these impingement incidents likely impacted population growth.

Adults

A large aggregation of adult rainbow smelt was observed in the Jones River during two of our daytime trips to the river (14 and 17 April 1998). The fish were congregated in a pool in Zone A (Figure 6). Based on past observations, this is indicative of a relatively strong spawning run. These fish were likely males, with females moving onto the spawning ground during the nighttime hours (Lawton et al. 1990).

During the 1998 spawning season, Eel River, Town Brook, and Smelt Brook (other tributaries in the PKDB complex) were inspected weekly for egg deposition. We sampled areas of known spawning activity based on past observations. Town Brook and Smelt Brook contained small patches of light egg sets. We did not find any eggs in Eel River for the second consecutive year. The majority of smelt spawning activity for the local PKDB smelt population again occurred in the Jones River.

2. Winter Flounder

Background

Winter flounder range the northwest Atlantic from the Gulf of St. Lawrence to Chesapeake Bay (Bigelow and Schroeder 1953), being found in water temperatures between 0 and 27°C and salinities from 4 to 30‰. They can form discrete, resident populations which undertake localized seasonal movements (Perlmutter 1947; Saila 1961; Howe and Coates 1975). Flounder movement and migration are apparently temperature driven (Pearcy 1962; McCracken 1963; Scarlett 1988; Powell, R.I. DEM, unpublished data). Some adults emigrate from shoal waters when water temperatures rise above 15°C and return as waters cool below this level. Other groups of winter flounder are resident, and, although an avoidance temperature of 24.4°C was reported by Meldrim and Gift (1971), their year-round occurrence has been documented in some estuaries (Olla et al. 1969; Wilk et al. 1977) at water temperatures around 24°C. In addition, Phelan (1992) found adult winter flounder throughout the year in an offshore area of New York and New Jersey.

Based on a meristics' study, Pierce and Howe (1977) concluded that estuarine groups of winter flounder do not necessarily constitute separate genetic, biological units. A group may be comprised of an assemblage of adjacent estuarine spawning units that intermix, of which some may be more geographically isolated than others. Homing patterns have been documented to some estuaries (NUSCO 1986; Black et al. 1988; Scarlett 1988; Phelan 1992; Powell, RIDEM unpublished data), and several tagging studies (Lobell 1939; Perlmutter 1947; Saila 1961; Howe and Coates 1975) have provided evidence of high fidelity to specific embayments for spawning following offshore migrations in consecutive years. At the same time, some winter flounder disperse to distant locations (Saila 1961; McCracken 1963; Howe and Coates 1975; Phelan 1992), and there may be a random search back for the natal spawning grounds (Saila 1961), following random food searches (McCracken 1963). Phelan (1992) speculated that populations may be discrete only during the spawning period, with random temperature-related seasonal movements resulting in an intermix at other times of the year. If the search for natal spawning grounds has a random component to it, then some winter flounder may be found in non-natal locations during the spawning season. From mark and recapture work in the inner New York Bight, Phelan (1992) purported that winter flounder there formed a dynamic assemblage, consisting of three reproductively discrete spawning sub-populations: one that "homes" to natal spawning grounds in the Navesink and Shrewsbury Rivers, a second consisting of an aggregation of generally sedentary fish found in Sandy Hook and Raritan Bays, and a third group found offshore, with all three capable of intermixing.

In Massachusetts, Lux et al. (1970), Howe and Coates (1975), and Pierce and Howe (1977) concluded from meristic and tagging work that, for management purposes, winter flounder consist of three stocks - one north of Cape Cod, another south and east of Cape Cod, and the third on Georges Bank. A comprehensive winter flounder mark and recapture program (more than 12,000 fish tagged at 21 locations) was conducted in Massachusetts during the 1960s by Howe and Coates (1975), who found that flounder migration generally encompassed relatively short distances; although, extensive movements of some tagged fish did occur. Flounder dispersal, overall, was greater south of Cape Cod, where many areas are shoal (<18.3 m) with waters warming considerably during the summer. Returns from release sites north of Cape Cod revealed that movement generally was more limited, with many tagged fish recovered in respective subarea release sites, even years later.

Winter flounder spawn principally at night when water temperatures are at or near the lowest (0 - 5 °C) for the year, occurring during late winter and early spring. Spawning occurs in estuaries (bays, rivers, harbors), over shoals outside estuaries, and on offshore banks. It usually takes place in the shallows over firm bottom, e.g., gravel, sand, eelgrass, and pelagic algae. The eggs are demersal and adhesive, and those that fall onto soft, fine sediments or onto algal mats are less likely to develop. Hatching occurs in about two to three weeks at water temperatures of 3-5 °C. Larval stage duration generally is 4-6 weeks, and the pelagic larvae, which are relatively non-buoyant, can move vertically in the water column, thus somewhat offsetting the effects of a diffusive environment. Age-0 fish (juveniles) are more tolerant of higher water temperatures than are the adults, and they often remain in estuarine nursery areas throughout their first year; age-1 fish may do the same (Buckley 1982).

The PKDB estuary, not far from PNPS, is a local spawning ground for winter flounder, although spawning also occurs outside this estuary. The adult segment of the local population is exploited prior to the spawning season by a regulated commercial otter trawl fishery that is open from 1 November to 31 January, with a minimum legal fish size of 305 mm TL. In past years, this fishery was open into the spring, but declining flounder abundance prompted a mandated reduction in temporal effort.

Spawning success, recruitment, and population coherence are maintained where physiography and oceanographic circulation enhance larval retention in specific geographic areas. Size of the spawning grounds and larval retention areas are limiting factors to absolute population abundance. Winter flounder population size is a function of the size of the physical system underlying larval retention. Large populations generally are found in large bays and on large offshore banks; whereas, smaller populations are associated with coastal ponds (lagoons) and smaller estuarine river systems (Howell et al. 1992). Clearly, the magnitude of impact of a given mortality (power plant related or otherwise) is inversely related to the absolute abundance of the population affected.

Habitat and water quality can be issues on inshore winter flounder spawning and nursery grounds because these areas typically are subject to anthropogenic alterations and environmental degradation. The various flounder life stages can be affected by dredging, filling of wetlands, toxicants, disease infestation, hypoxic conditions, and power plant-induced mortality. Direct mortality, loss of habitat, along with the loss of reproductive and growth potential can result. In addition to natural and fishing mortality, impingement and entrainment of winter flounder by power plants can substantially add to total mortality. Losses may be especially problematic when power plant intakes are located in or near spawning and/or nursery grounds (Normandeau 1979), e.g., at PNPS. All life stages of winter flounder, at least seasonally, inhabit the artificial intake embayment at PNPS, which simulates a small cove.

Eggs and Larvae

The larvae of winter flounder are much more susceptible to power plant entrainment than are their eggs, which are demersal and adhesive. The benthi-pelagic larvae, especially the later stages, generally are more abundant near the bottom of the water column during the daytime and, thus, are vulnerable to entrainment as bottom water is drawn into the intake structure. At PNPS, entrainment of winter flounder larvae has ranged from an estimated 3.5 to 88.8 million annually over the last 19 years (1980 to 1998); the 1998 estimate was, by far, the highest recorded during this entire period. Larval entrainment was substantially up even from 1997 (55.4 million larvae), which represents the second highest annual entrainment of the time series. The third highest value of this period was 29.8 million larvae, which was recorded in 1981. We pondered the cause for the large increases in larval entrainment the last two years. From the Massachusetts Division of Marine Fisheries' (MDMF) coastwide spring trawl-survey time series, we find that the survey biomass index for the Gulf of Maine winter flounder stock did not substantially increase in 1997, suggesting that flounder numbers were not particularly higher that year. Overall, their spring surveys show record high indices of recruitment of age-2 flounder since 1992. However, through 1997, we found no correlation between the number of larvae entrained at PNPS and the surveyed number of age-2 fish, using a two year lag. Values for the 1998 MDMF spring survey were not available at this time

By way of comparison, the total number of larval winter flounder entrained in 1996 and 1997 at the Millstone Nuclear Power Station in Connecticut was estimated to be 53.9 million and 78.5 million, respectively, which represented the second and third lowest entrainment levels since three-unit operation began in 1986. Larval flounder entrainment at the Brayton Point Power Station in Somerset for 1996-1998 was estimated at 116.4 million, 96.9 million, and 49.0 million, respectively, which represent relatively low values for that power station; the 1998 value represents the lowest entrainment level ever at that plant.

Larval mortality due to entrainment at PNPS in 1998, assuming no survival and using the Adult Equivalent Model with staged data, which assumes population equilibrium and no density-dependent compensation, equates to the total loss of 77,428 age-3 winter flounder. This estimated loss to the local population is 64% greater than last year's projected loss of 47,087 adults. Entrainment losses at the station for the last 12 years have ranged annually from 2,619 adults (1987) to this year's high of 77,428 adults. The equivalent adult estimates (stage specific) for entrainment at Brayton Point Station for 1996-1998 were 32,192, 35,806, and 23,419 age-3 winter flounder, respectively. Gibson (1994) examined data for several winter flounder populations and found that after accounting for adult mortality, recruitment rates were lowest in three populations (located in Mt. Hope Bay, Niantic River, and off Plymouth in western Cape Cod Bay) that are subject to entrainment by nearby power plants.

Delimiting the geographic extent of the local population was important to establish the source of flounder larvae entrained at PNPS. This power plant has been shown to entrain larval winter flounder produced in PKDB and also larvae produced from sites outside the estuary in western Cape Cod Bay (Marine Research, Inc. 1988).

Juveniles

In 1998, an estimated 1,493 winter flounder were impinged at PNPS. All were juveniles (ages 0 and 1). Winter flounder were impinged during all seasons of the year, with the highest numbers collected in the month of April. The number impinged this year (1998) represents about 109 age-3 adults.

Juveniles tolerate water temperatures up to 27°C, but sublethal effects begin to appear at 20°C, with feeding inhibition evident at 24-27°C. This should preclude juveniles from the immediate discharge area in late summer, when temperatures can exceed these values.

Adults

Direct mortality of winter flounder has been rare in the thermal plume off PNPS. When exposed to high water temperatures, flounder probably vacate an area or try to avoid thermal stress by burying into the bottom which would be cooler than the overlying water (McCracken 1963; Olla et al. 1969). Adult flounder can tolerate water temperatures up to 26°C, but above 22.2°C they become inactive and cease feeding. Occasionally during past summers, bottom water temperatures have approached 30°C at the mouth of the PNPS discharge canal.

Stone and Webster (1977) predicted that adult winter flounder would be excluded by thermal stress from the immediate vicinity of the Pilgrim discharge during late summer and early fall, although this impact area is small, at most likely less than 4,047 m^2.

Seven winter flounder reportedly were caught by anglers at Pilgrim Shorefront in 1998. In the 1970s and early '80s, this species ranked among the top five sportfish angled in the recreational fishery off the power plant.

Movements, Migration, Fidelity and Abundance

To assess the magnitude of larval winter flounder entrainment at PNPS, we have conducted a tagging experiment of sub-adult and adult winter flounder in the inshore waters of Western Cape Cod Bay/Massachusetts Bay. The ecological significance of man-induced mortalities (e.g., via power plant water withdrawal/discharge heat effects) is difficult to interpret unless the mortality can be evaluated against some measure of the size of the true biological population affected, while also considering natural mortality estimates. Our objectives have been to define movements, migration, and discreteness (i.e., fidelity to a spawning area) of the local population and to estimate its absolute abundance. This section relates to our analysis of observations pertaining to the movements, migration, fidelity and abundance of winter flounder on coastal grounds north of Cape Cod.

The geographical boundaries defining the region of the sample population for our tagging were defined for us by Eric Adams of M.I.T. employing an analytical, hydrodynamic model to predict spatial estimates of the origin of winter flounder larvae that are subject to be entrained at PNPS. This simplistic model outputted the cumulative probability density function of entrained organisms (larvae) at the power plant that originate from different locations. The question of larval transport was deemed analogous to the problem of computing the relative concentration of a contaminant released at some origin at a constant mass moving in one direction by a current of constant magnitude.

From the F/V *Frances Elizabeth*, we caught and tagged winter flounder, and recaptured tagged fish to determine fidelity and to estimate absolute population abundance employing mark and recapture models.

Between 30 March and 9 May 1998, we successfully completed 198 standard trawl tows within the study area and caught a total of 17,409 winter flounder for a mean catch of 87.9 fish per tow (CPUE). Of the 15,042 flounder sampled during the 171 tows used for tagging purposes, 7,494 (≥280 mm TL) or 49.8% were tagged, with a mean number tagged per tow of 43.8. It should be noted, however, that there were probably multiple recaptures of some smaller, untagged fish. In comparison, in 1997 we made 94 trawl tagging tows, sampling 11,792 winter flounder, of which 7,487 (≥250 mm TL) or 63.5% were tagged. The mean CPUE was 149.2 winter flounder; whereas, the average number tagged in a tow was 79.6. The CPUE data suggest that relative abundance of winter flounder in the study area was considerably higher in 1997 than in 1998.

From 1993 to 1998, we marked/tagged 22,476 winter flounder during the spring spawning season from Humarock to Manomet Point (Figure 7) in Zones 1-3 (defined study area - Figure 8) of western Cape Cod Bay (Table 2). The number and minimum size of fish marked or tagged by year was: 1993 - 206 fish (≥ 25 cm TL); 1994 - 245 fish (≥ 20 cm TL); 1995 - 2,047 fish (≥ 20 cm TL); 1996 - 4,997 fish (≥ 25 cm TL); 1997 - 7,487 fish (≥ 25 cm TL); and 1998 - 7,494 fish (≥ 28 cm TL). All fish were released in the general vicinity of capture. Tag returns came from commercial and recreational fishermen, fish processing plants, and our research efforts.

From the F/V *Alosa* we collected catch data and recapture information inside and outside the collective tagging area (Areas 1-3) to determine fidelity and to estimate absolute population abundance via density extrapolation. Between 30 March and 8 May 1998, we successfully completed 160 standard trawl tows, catching a total of 12,492 winter flounder for a mean CPUE of 78.3 fish.

The population of winter flounder in the environs of Plymouth is demographically open and thus subject to immigration and emigration. Our analysis is based on winter flounder tag returns obtained with accurately reported locations through 31 December, 1998 (Table 2). In some years, well over 50% of our tag returns came from commercial fishing catches.

Through December 1998, 896 fish (with accurate return information) have been recaptured for an overall return rate of 4.0% (Table 2). A recapture rate of 2.8% was reported by Phelan (1992) from 7,346 winter

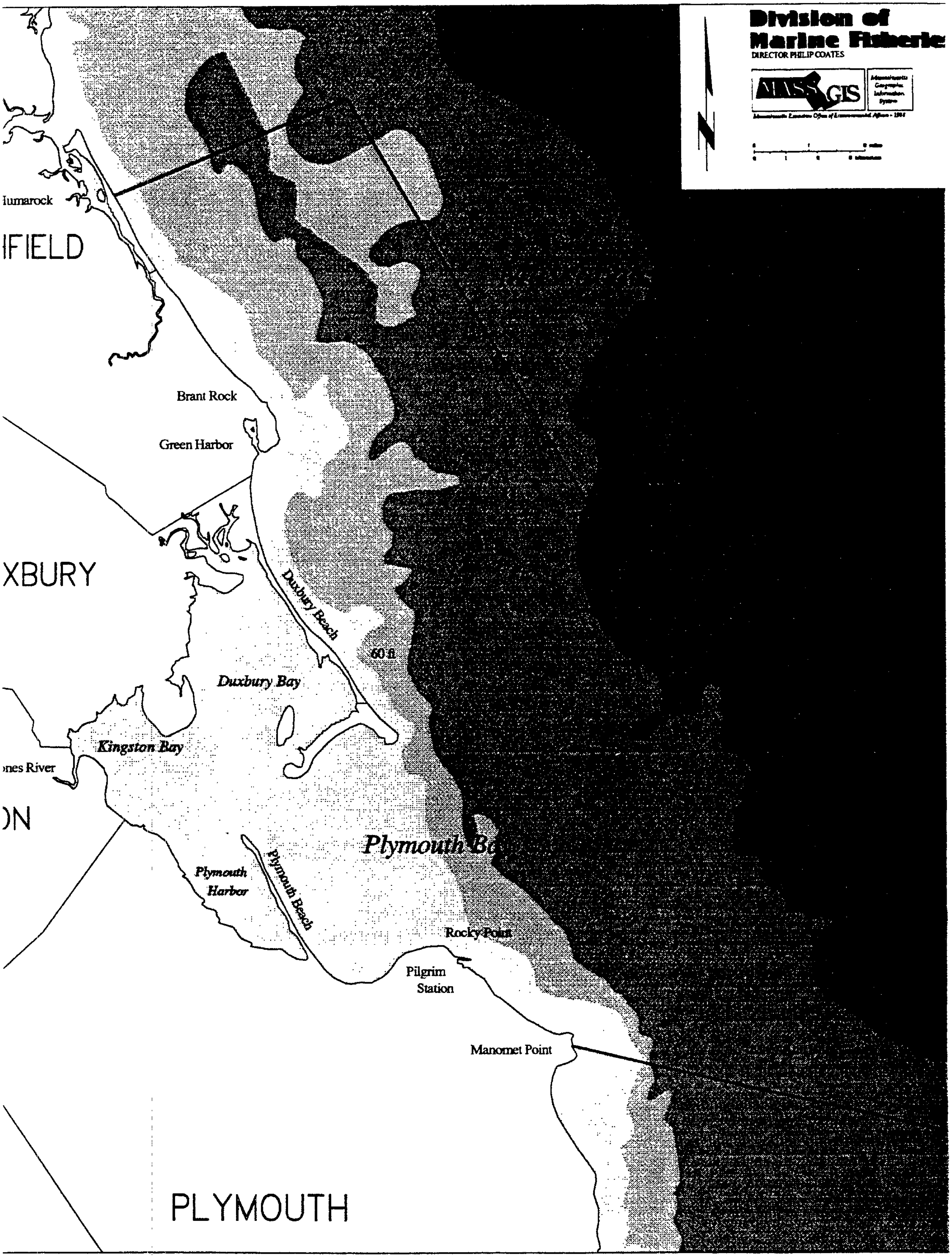

Figure 7. Division of Marine Fisheries Winter Flounder Tagging Area

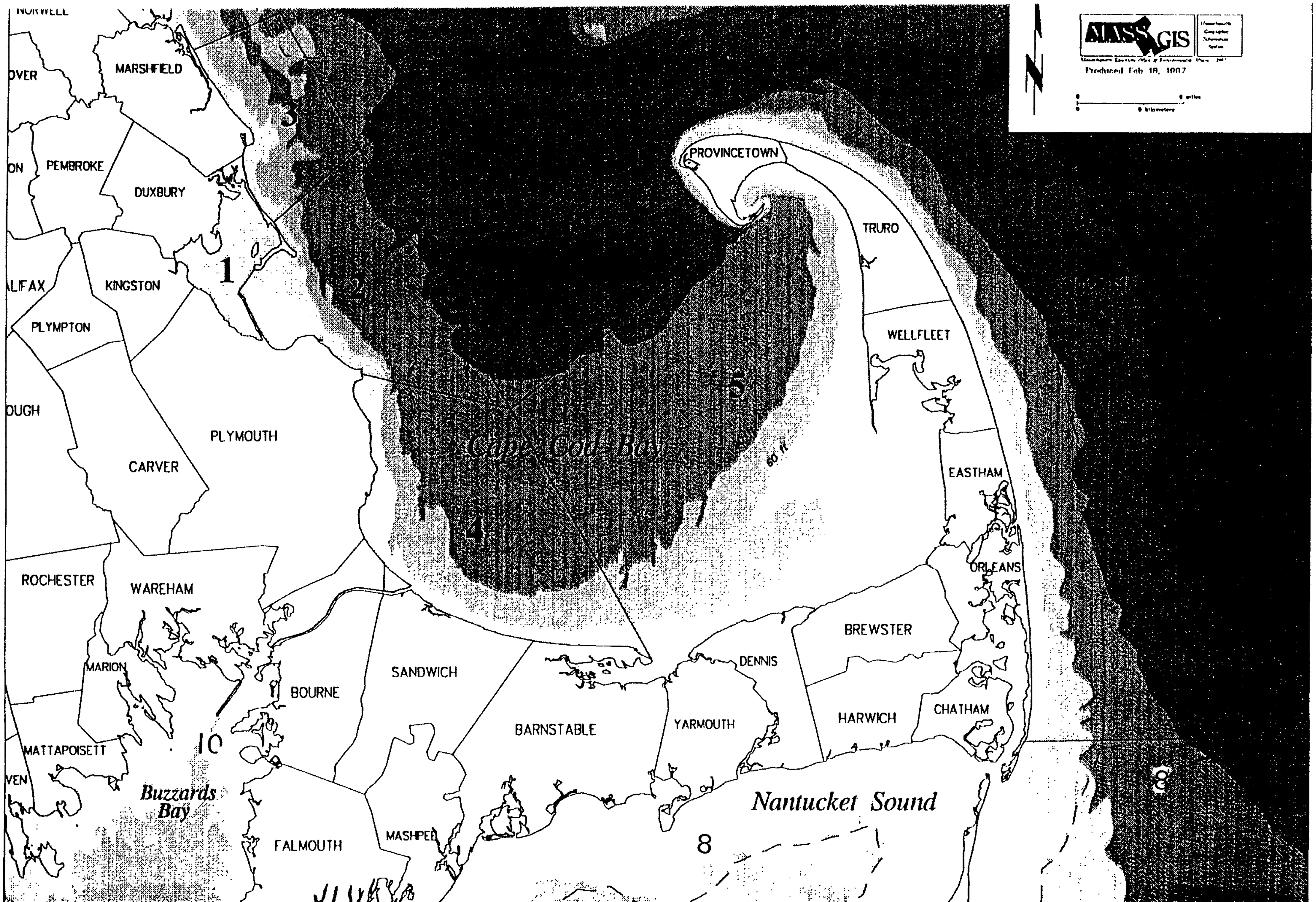

Figure 8. Recapture zones of winter flounder (<u>Pseudopleuronectes americanus</u>) tagged in areas 1-3 by the MA Division of Marine Fisheries in the decade of the 1990's

flounder ($\geq$ 18 cm T.L.) tagged in the inner New York Bight in the late 1980s. In many fish mark and recapture programs, the percentage of returns ranges from 3 to 10%. By way of contrast, over 30 years ago, Howe and Coates (1975) of the Massachusetts Division of Marine Fisheries, having tagged 12,151 winter flounder (generally $\geq$ 200 mm TL) in the 1960-1965 period (late March-April) at 21 locations along the Massachusetts

Table 2. Summary of winter flounder mark/recapture data from western Cape Cod Bay in the 1990s.

Tagging dates	Size-total length	Number tagged (fin-clipped)	Color of tag	Recaptured through 31 Dec, 1998	% Recovery
Jan-May/Nov-Dec, 1993	≥25 cm	(206)	-	2	1.0
Mar-May/Nov-Dec, 1994	≥200 mm	226	yellow	27	12.0
April, 1995	≥200 mm	2,066	yellow	86	4.2
April, 1996	≥250 mm	4,997	red	191	3.8
Mar-May, 1997	≥250 mm	7,487	blue	385	5.1
Mar-May, 1998	≥280 mm	7,494	green	205	2.7
Totals	-	22,476	-	896*	4.0

* This figure does not include 88 tag returns from fish processing plants where there were incomplete reportings of recapture locations.

coast, obtained 4,440 tag returns through September 1971 for a remarkable overall finfish recovery rate of 36.5%. One of the tagging locations was Plymouth Outer Harbor, which is within our defined study area, where in 1964 they tagged 500 winter flounder, of which 36.6% eventually were recaptured. It should be noted that their returns were compiled for a longer period of time following flounder tagging.

The overall tag return rate, to date, of 4.0% is disappointing for the number of fish tagged in the study area and is a limiting factor to our drawing inferences from the subset of measurements obtained from the sample population. We believe that the low return rate is due to the under-reporting of recaptures by commercial fishermen and the spatio-temporal bans on commercial fishing in the inshore waters. The exclusion of commercial fishing from inshore waters at times during the year effectively removes a substantial source of recapture information. From anecdotal comments, we have been told that some commercial fishermen did not return recapture information to us because they believe the data will be used against them for management purposes. Our offering of lucrative financial rewards the last two years, via lottery, aided somewhat in obtaining tag returns, based on our conversations with certain individuals reporting tags. The number of unreported tag returns is unknown; however, we suspect it to be sizable within the commercial sector.

Tag returns by area for winter flounder recovered during the non-spawning period (June-February) from 1993-1997 and (June-December) of 1998 (Table 3) must be interpreted with some caution because of the distribution of fishing effort off the Massachusetts coast, which, in turn, is dependent on seasonal flounder distributions and fishery closures. It is clear that there was an unequal distribution of commercial fishing effort spatially. The highest numbers of recaptures, by far, came from Area 2, which was within the overall tagging

Table 3. Tag returns by area for winter flounder (at large at least one month) recovered during the non-spawning period (June-February) from 1993-1997 and (June-December) of 1998. Fish were marked in Areas 1-3.

Area	Number of Recaptures	Percent of Total Recaptures
1	20	3.4
2	318	53.6
3	48	8.1
4	68	11.5
5	15	2.5
6	29	4.9
7	65	11.0
8	1	0.2
9	5	0.8
10	0	0.0
Other*	24	4.0
Totals	593	

*Other: Newport, R.I. (2), Stellwagen Bank (15), Highland Light (3), Georges Bank (3), Long Island, NY (1).

area. This suggests that a sizeable proportion of the flounder may not move far afield from the overall tagging area (Areas 1-3) after the spawning season (March-May). Awareness of fishermen in this area of concentrations of flounder and numbers of tagged fish (including the two commercial vessels we contracted for tagging/recapture operations) may have contributed somewhat to recaptures from here. Relatively high recapture numbers just north (Area 7) and south (Area 4) of our overall tagging area are similar, reflecting fish dispersal in both directions. A small number of recaptures came from Area 6 off Provincetown, indicating an eastward movement of some fish. A few individuals traveled considerable distances, having been reported from Georges and Stellwagen Banks; the backside of Cape Cod (Highland Light); Gay Head, Martha's Vineyard; Newport, R.I.; and Long Island, N.Y. The greatest straight-line distance from tagging area to recovery site was a remarkable 170 miles, accomplished by a 42 cm female in a span of 7 months and taken off Long Island, New York. It is evident that flounder were more broadly distributed geographically outside the spawning period.

Tag returns recovered during the spawning period (March-May) from 1993-1998 (Table 4) also are influenced by the distribution and seasonality of fishing effort off the Massachusetts coast. Many of the recaptures in Area 2 are from our contracted vessel(s) during tagging operations. There is limited commercial fishing allowed in Areas 1-5 during this March-May period based on state-mandated spawning closures, while recreational winter flounder fishing does not open until May 1. Fidelity of the local flounder population has been somewhat difficult to assess based on the inherent areal biases associated with tag return information. However, aboard contracted vessel(s) we have recaptured high numbers of flounder in Area 2 (part of the tagging area) during the spawning season (Table 4). Fish recovered from Areas 6 and 7 (Massachusetts Bay) may have already spawned and then moved off the local spawning grounds. Seventy-two percent of the total recaptures came from Area 2 during the spawning season.

Additional information about fidelity of winter flounder to the study tagging area came from our other research recapture work conducted from late March through early May, 1998. A second contracted commercial fishing vessel (F/V *Alosa*) made haphazard trawl tows (totaling 110) in Areas 4 and 5 (outside our tagging

Table 4. Tag returns by area for winter flounder (at large at least one month) obtained during the spring spawning season (March-May) from 1993-1998 of fish tagged in Areas 1-3.

Area	Number of Recaptures	Percent of Total Recaptures
1	1	0.3
2	218	71.9
3	0	0.0
4	35	11.6
5	4	1.3
6	16	5.3
7	27	8.9
8	0	0.0
9	0	0.0
10	0	0.0
Other*	2	0.7
Totals	303	

*Other: Stellwagen Bank (1), Highland Light (1)

area) searching for tagged fish from past years of the survey. Only 2 tagged fish (at large at least one year) were recovered. We attempted trawling for tagged flounder north of the tagging area (Area 7), but untrawlable bottom limited the number of standard tows (3) we could successfully complete in this area. No tags were recovered. The data strongly suggest, nevertheless, that winter flounder return to (or never stray very far from) the locality of tagging with high frequency.

In summary, the returns from our release sites show overall relatively limited (localized) movements, basically confined to inshore waters. Thus, our data support findings from earlier studies that most observed movements of winter flounder located north of Cape Cod are restricted to relatively short distances. Finally, it appears there is fairly high fidelity and thus discreteness in the localized population within the Plymouth area, which imparts more importance to entrainment effects of PNPS. Nevertheless, geographical isolation during the spawning period is not complete in that there is some exchange with adjacent populations, with tagged fish being recaptured during this time interval in adjacent areas.

Density extrapolation (Area Swept Method), post-stratified by depth, was used with data collected from 28 trawl tows made on the F/V *Alosa* over the period of 25 to 29 April, 1998 to estimate winter flounder population size : one estimate was for a segment of the flounder population ≥ 280 mm TL (age 3 and older considered to be adults) and the other for the entire winter flounder population (all sizes) (Table 5), with areal measurements estimated for MLW.

Our unadjusted estimates of winter flounder absolute abundance for the study area (see Methods section, this report) using area-swept are 132,406 adults and 294,225 total winter flounder. These estimates assume a trawl gear efficiency of 100%. Trawl catch efficiency is variable rather than a constant; we assumed it was more likely closer to 50%. Thus, we doubled the estimates and the adjusted values were 264,812 adults and 588,450 total flounder (Table 5). Last year's area-swept estimates for adult and total flounder abundance were higher at 321,832 and 905,031, respectively. This also suggests that abundance was down in 1998. Precision improved with post-stratified estimates of abundance.

In 1999, we will pre-stratify our standardized sampling methodology based on depth prior to sampling, in a continued effort to reduce the variation around our density estimates. Gear selectivity is a factor, in that, the

Table 5. Estimated abundance (post-stratified by depth) in numbers of winter flounder (bottom area calculated at MLW), with 95% confidence limits, of winter flounder ≥ 280 mm (TL) and for pooled lengths estimated by otter trawl density extrapolations (adjusted for gear efficiency) in the Pilgrim study area, spring 1998.

	Total Bottom Area (square meters)	Number of flounder	Upper 95% CL	Lower 95% CL
Flounder ≥ 280 mm TL	267,391,497	264,812	286,825	242,799
All Flounder	267,391,497	588,450	623,570	553,330

F/V *Alosa* used a 4.5 mm mesh cod-end which limits the retention of small fish; thus, an expanded estimate of abundance is biased toward larger fish. There is spatial variation in abundance of this species by depth (Lawton et al. 1995), and we have not always distributed our sampling effort based on the relative areal sizes of each depth stratum. It is noted that the adult estimates for 1997 and 1998 are for a larger study area than used for the previous two years. Based on a modeling prediction of the origin of winter flounder larvae potentially entrained, we expanded the study sampling area, substantially increasing areal coverage. Based on the modeling by Eric Adams of M.I.T., it is predicted that winter flounder larvae entrained at PNPS can come from as far away as 17.7 km. To repeat, our present study area encompassed from Humarock, Marshfield south to Manomet Point, Manomet (Figure 1).

To gain perspective on the entrainment equivalent adult estimate, we compared it with population estimates generated for the study area. These estimates came from two methods - trawl area-swept and mark-recapture. First, a percent loss of adult winter flounder as a result of larval entrainment was obtained using the equivalent adult estimate (77,428) obtained from entrainment monitoring and the Adult Equivalent Model as related to the area-swept estimate of the number of adults (264,812) residing in the study area in 1998. The adult loss because of entrainment corresponds to 29.2% of the adults estimated to be residing in the study area during the 1998 winter flounder spawning season. Estimated adult stock reduction due to entrainment in 1997 was 14.7%, based on an area-swept estimate of adult abundance. However, it should be remembered that larvae of a given year will not attain adult status until age 3, so the actual effects of entrainment in 1997 and 1998 won't be realized until winter flounder population estimates for the years 2000 and 2001 are generated.; the effect could be less or more than the current estimates. A review by Marine Research, Inc. (1986) of winter flounder early-life studies at PNPS revealed that stock reductions of 0.7 - 2.2% (relative to a larger stock size back then) were estimated to be possible because of plant operations. It is noted that back in the early 1980s, winter flounder were in greater abundance than at present. Given that coast-wide winter flounder populations have been severely depressed in recent years by overfishing , PNPS entrainment may have added markedly to total mortality affecting this fairly discrete population in recent times. However, we know from our tagging data, fidelity is not 100 %, with some mixing going on with other nearby spawning units.

Population estimates for 1998 with confidence limits, obtained from various mark-recapture models, are found in Table 6. As to the five tagging models used to estimate adult population size (fish ≥ 280 mm TL), the estimates range from 7.6×10^4 to 1.1×10^5. These estimates predict that abundance was down from last year (1.2×10^5 to 5.2×10^5). All were hampered, however, as to predictive value because of the continued overall low number of tag returns; in fact, we could not use the Mark program model this year at all (not listed in Table 6). The Petersen model is the simplest estimator but had a bias in that we did not know how many unmarked fish of

Table 6. Mark-recapture model estimates, with 95% confidence limits, of absolute abundance of winter flounder ≥ 280 mm TL in the Pilgrim study area, spring 1998.

Model	Number of Flounder	Lower 95% CL	Upper 95% CL
Petersen	111,195	91,147	142,547
Schnabel	92,659	82,597	105,514
Schumacher	98,890	86,455	115,502
Capture	104,429	93,053	117,318
Jolly-Seber	76,259	54,744	106,266

≥ 280 mm TL were involved in multiple recaptures during the last 4 days of the study, when no fish were tagged. With the Jolly-Seber open population model, we could not generate an estimate with high precision because of overall low recaptures and based on the chi-square goodness-of-fit test, model adequacy to parameterize the population was constrained. Of the tagging models employed, the Capture model was preferred because it best fit the data; furthermore, it is the most commonly used model for capture-recapture studies where capture probabilities vary only by time (although changing environmental conditions can affect capture probabilities).

The estimated adult loss of winter flounder (77,428 fish) in 1998 because of larval entrainment (88.8 million larvae) at PNPS was compared to the Capture mark/recapture model estimate of spring 1998 abundance of adults in the local population. The entrainment loss as a percent of estimated abundance of extant winter flounder $\geq$ 280 mm TL present in the study area during the 1998 spawning season was 74% (Capture model). Intuitively, when examining entrainment numbers for 1998 and the equivalent adult estimate, and comparing the latter to population estimates of adults obtained by area swept and the Capture model of tagging data, one would be concerned that the impact of PNPS, at the level of entrainment that occurred in 1997 and 1998 was ecologically significant to the local winter flounder population. We would deem the loss of over 77 thousand age-3 fish via entrainment by PNPS to be an important source of additional mortality to an already stressed population from overfishing.

In retrospect, we selected the Capture Model population predictive estimate which best fits the flounder data and compared entrainment impact at PNPS to that at the Brayton Point Station. Gibson (1994), using data collected prior to the winter flounder stock decline in Mount Hope Bay in the mid-1980s, applied four methods of estimating population size, and generated an average population estimate of 378,957 fish (confidence limits of 40,000 - 718,000). The average loss to entrainment of 32,829 age-3 fish (unstaged approach) represented 82% of the lower confidence limit of the absolute abundance estimate and 5% of the upper limit. At PNPS, the population estimate for 1998 via the Capture Model was 104,429 fish with confidence limits of 93,053 - 117,318. The loss to entrainment of 77,428 age-3 fish (staged approach) amounted to 83% of the lower confidence limit and 66% of the upper confidence limit.

3. Other Species

Data on other finfish species were obtained from a creel survey conducted at the PNPS Shorefront Recreation Area and by underwater SCUBA surveys in the thermal discharge area.

Creel Survey

Unlike many past years, the access of recreational fishermen to the Pilgrim Shorefront was attenuated in 1998 because the area was closed to the public for nearly two months (28 August - 23 October) while the discharge jetties were being reconstructed. Therefore, the creel survey of shore-based anglers at the Shorefront was conducted from 4 April through 27 August, and again from 24 October through 29 November, when the Shorefront closed for the season. A total of 986 anglers was interviewed of the 1,877 anglers tallied during 121 sampling days over the split season. This represented 56 fewer sampling days than last year. The goal was to obtain basic information on sportfishing activity, including fishing effort and locations, and gamefish catch over time. There were two data collectors, who were seasonal public relations personnel for BECo; they conducted the creel inventory in addition to other duties. We requested them to interview at least 10 anglers per day (5 in the morning, 5 in the afternoon). If there were 10 or less individuals, then each fisherman was represented in the census for that day. On days with greater than 10 fishermen, catch reports were expanded to the total number of fishermen based on the catch results of the 10 anglers interviewed. Only weekends were sampled in April, May, late-October, and November, while there was daily coverage June through 27 August.

It is clear that most of the fishing effort was expended in the thermal discharge area from off the two discharge canal jetties. Some effort was expended off the outer breakwater, with even less effort off the rocky beach located north of the discharge canal. Anglers primarily sought striped bass (*Morone saxatilis*) and bluefish (*Pomatomus saltatrix*), with not much directed effort for groundfish.

The overall monthly average number of angler trips per day to the Shorefront in 1998 was 15.5, while individual monthly averages ranged from a low of 3.5 in November to a high of 43.8 in May; the high values reported for May are probably influenced by the fact that only weekends were sampled, when angler presence is substantially greater. Effort was relatively uniform from June through August, ranging from 12.6 to 15.7 angler visits in a day.

The recorded sportfish catch totaled 1,553 fish, comprising four species : bluefish, striped bass, winter flounder, and tautog (*Tautoga onitis*). The overall mean catch rate (i.e., catch per angler trip) was 0.83, with a monthly range of 0.0 (April) to 1.31 in October. Reported catches were up from last year, when the overall mean catch rate was 0.34 fish per angler trip; the change in catch rate may be influenced by the manner in which data were recorded this year (namely, subsampling 10 anglers on busy fishing days) and the resulting expansion factor applied to subsampled interview data. We believe that creel data recorded in past years may have under-represented the actual catch, as a limited number of the total anglers present on a busy fishing day were interviewed, with no adjustment made for the creel of fishermen not interviewed.

In 1998, the percent composition of the overall recreational catch was 72.3% striped bass, 27.2% bluefish, 0.4% winter flounder and 0.1% tautog. Highest monthly catch (pooled species) occurred in July at 524 fish or 33.8% of the 7-month total, followed by June (416 fish - 26.8%) and August (305 fish - 19.6%).

Winter flounder, which were not recorded in the sportfish catch of last year, were caught in July (3 fish) and August (4 fish). No Atlantic mackerel (*Scomber scombrus*) were reported for this year.

Striped bass dominated the monthly totals of May, July, August and October, being caught in all months of the survey except April. The first striped bass was landed on 3 May, which is typical for their appearance in the sportfish catch at the Shorefront. Of the 1,122 striped bass reported to be caught at the Shorefront in 1998, 96.7% were sublegal as to the recreational size limit (< 71.1 cm TL). The highest monthly catches were made in July (40.0% of total striped bass catch), followed by June (19.2%) and August (18.8%). The overall catch rate, i.e., catch per day, averaged 9.3 striped bass, with monthly rates from May-October ranging from 7.2 to 17.9. These catch rates were up substantially from last year. The seasonal catch of striped bass was similar in May and June, then improved in July, when bass were angled in all but four days. Catches declined somewhat in August, at which point the Shorefront construction closure occurred. For the 3-day sampling period when the Shorefont re-opened in October, the catches were relatively high, followed by a rapid decline in November.

The total striped bass catch in 1998 was 76% greater than that recorded for 1997, even with the construction closure. The reason for the catch increase is unclear, but a much more plentiful supply of striped bass along the Atlantic coast in recent years ostensibly should have resulted in elevated catches of this species at the Shorefront this year and last year. We already mentioned that the change in this year's sampling design may have contributed to higher values of fish being reported relative to past years.

The PNPS's warm-water discharge has attracted striped bass over the years when the plant has been operating with both circulating seawater pumps in use. We observed about a dozen "overwintering" striped bass in the discharge canal while SCUBA diving in December 1998. These fish are susceptible to cold shock if PNPS was to experience an outage during the winter months. The most recent observational dive occurred in January of 1999 in the thermal discharge; we sighted about 40 striped bass residing there. A plant outage was planned for February 1999.

Bluefish were first caught on 24 May, 1998 and were abundant in the catches of June-August and October. A total of 423 bluefish in a range of sizes was recorded at the Shorefront, with catches highest in June (47.3% of total). Catch rates (i.e., catch per day and catch per angler trip) matched up well with the monthly totals (excluding October, which was based on only three days of sampling): the former ranging from a mean of 2.3 fish per day in July to 6.7 fish per day in June, with the latter ranging from 0.10 fish per angler trip in July to 0.42 in June.

The 1998 bluefish catch at the Shorefront declined 43.6% from that in 1997. The reason for the decline is speculative, but may be partially the result of the Shorefront closing for nearly two months (September-October). We also cannot rule out a real decline in bluefish numbers in the area. Nevertheless, it is readily evident that when PNPS is operating, the warm-water discharge current attracts and concentrates bluefish as well as striped bass, which is advantageous to sportfishermen. Recreational bluefish catches at PNPS have been notable as to the number landed over the years when the station is operating. Conversely, power outages at the Station have resulted in markedly reduced sportfish catches at the Shorefront (Table 7).

Table 7. Recreational bluefish catches reported by creel survey over three decades at the Pilgrim Station Shorefront in relation to plant operation

Year	Number of Bluefish	Reported Period	Plant Status
1973	500	September-October	On-line
1974	700	September-October	On-line
1975	14	September-October	Off-line
1983	1,200	June-November	On -line
1985	2,200	June-November	On-line
1984 & 1986	less than 100 fish for the two years combined	June-November	Off-line
1996	2,014	June-October	On -line
1997	750+	June-October	On-line
1998	423	June-November*	On-line

* Shorefront was closed August 28 - October 23 1998 due to construction.

Observational Diving

Underwater finfish diving observations provide us with visual data on occurrence and general abundance of finfish in the immediate area of the thermal effluent. From August through December, monthly SCUBA dives were completed, investigating the mouth of the discharge canal and the adjacent thermal discharge area. Small aggregations of cunner (*Tautogolabrus adspersus*) were present outside the canal mouth throughout the summer and early fall. Striped bass were the most commonly observed species, with numbers peaking in early September at 125 to 150 individuals per dive. Tautog were noted on all dives through early November, but following this they apparently had left the area as water temperatures declined. Their numbers ranged from 15 to 75 individuals per dive.

4. Impact Perspective

Winter flounder, rainbow smelt, cunner, alewives (*Alosa pseudoharengus*), and Atlantic silversides (*Menidia menidia*) have been negatively impacted by PNPS operations (Table 8). The response of these species to perturbation may be illustrative of power plant-induced stresses on other marine finfish in the area.

Table 8. A summary of mechanical impacts of Pilgrim Nuclear Power Station on selected finfish species and mitigation undertaken in the offsite waters of western Cape Cod Bay.

Species	Impact of Pilgrim Nuclear Power Station	Comments/Mitigation
Rainbow smelt	High plant impingements occurred in 1978, '93, '94. In 1993 and '94, alone, an estimated 20,000 smelt were impinged which is of concern considering the low numbers of the local population in recent years.	To remunerate for impingement losses, we stocked over 1.8 million smelt eggs over the years - 1994 and '95 - into the nearby Jones River, the prime smelt spawning ground. DMF also has worked to enhance spawning habitat on the Jones River smelt run by adding artificial plant substrate for egg deposition. An annual event since 1995, this effort is intended to improve instream egg survival. We recommend that this effort be ongoing. DMF has assisted with the removal of tree snags from the river, and we recommend that this and efforts to improve overall water quality be given top priority in future restoration efforts.
Winter flounder	In 1998, an estimated 88.8 million winter flounder larvae were entrained, which equates to the theoretical loss of 77,428 age-3 flounder (model estimated) from the local population. While this seeming abundance may be the product of a robust spawning season, it also may simply be the result of localized concentration by wind and water movement. Entrainment losses, equated to adults, ranged from 29 to 74% of the possible existing adults in the study area in 1998. An estimated 1,493 flounder were impinged in 1998; all were juveniles.	Absolute abundance of adult winter flounder (≥ 280 mm TL) in the study area during the spring spawning period of 1998 was estimated by density extrapolation to be 264,812 fish. Population estimates of winter flounder (≥ 280 mm TL) from a multiple census mark and recapture model was 104,429 fish for the 1998 spawning season. In April and May 1995, a plant outage was coincidently scheduled during the flounder spawning period. As only one circulating water pump was in operation, the volume of cooling water drawn into the plant was reduced by 50%, greatly diminishing concomitant entrainment of winter flounder larvae. It is recommended that plant outages be scheduled at this time of year as an attempt to minimize impact on this species, as well as other springtime spawners.
Cunner	Cunner eggs and larvae have been entrained at PNPS in large numbers each year of station operation. Because of the behavior of cunner on rocky reefs and the number of ledges in the PNPS area, it was difficult to determine population abundance and to assess plant impact. A recruitment approach to assess plant impact was undertaken from 1995-1997.	Of the reef areas (natural and artificial) sampled in the study area in past years for cunner mark and recapture, the largest sub-unit of the local population per unit area occurred off the outer intake breakwater, where estimates of cunner adults had approached 5,000 fish. Constructed to protect the intake from wave-related damage, the breakwater provides an abundance of structurally complex habitat critical to cunner survival. As such, construction of this structure likely allowed local cunner abundance to flourish beyond what could be supported naturally. In general, the data from three years (1995-1997) of recruitment studies suggest that PNPS had a minor effect on recruitment success of the local cunner population.
Alewife	In September 1995, about 13,100 juvenile alewives were impinged and presumed to have died. The potential for this or other species to be impinged in large numbers make future impingement monitoring advisable, so mitigative measures can be undertaken as necessary.	Natural reproduction was the exclusive means relied on to replace the lost alewives, and no restocking was recommended or conducted. However, we did recommend a measure of habitat rehabilitation. To improve the passage of spawning-run alewives in local streams, we obtained a sum of money from BECo that will be used to repair a fish ladder in the Pilgrim Station area.
Atlantic silverside	An estimated 11,900 Atlantic silversides were impinged in 2 separate incidents at PNPS, occurring in late November and late December 1994. This species is typically dominant and is impinged in high numbers, estimated at several thousand individuals annually during many of the past years at PNPS.	No compensatory action has been taken to date because the Atlantic silverside is short-lived, and prolific.

Rainbow smelt

In 1993 and 1994, rainbow smelt annual impingements at PNPS were relatively high - about 9,500 and 10,600 fish, respectively. Impingements of that magnitude are likely to be biologically important to the local smelt population. As a remedial measure to offset power station impact, we stocked over 1.8 million smelt eggs into the nearby Jones River (the major smelt spawning tributary in the area) over the years of 1994 and 1995. From 1995 through 1998, we also have employed egg collecting trays containing artificial plant substrate (sphagnum) in this stream to enhance spawning habitat for the purpose of optimizing egg survival to hatching. This latter effort will be continued in 1999.

Cunner

Entrainment of cunner eggs and larvae at PNPS has been high over the years. In 1997 alone, entrainment was equated to the equivalent loss of an estimated 498,281 adults from the local population. Entrainment of this magnitude would appear to be substantial, but the importance of this loss to the local cunner population is unknown. We have geographically bounded the local population which included all major recruitment sources. However, absolute abundance of the local population is difficult to determine because of logistics and financial constraints. Instead, for three years (1995-1997), we conducted recruitment studies to assess power plant effects of water withdrawals.

In 1995, cunner recruitment success appeared to be regulated primarily during the post-settlement period by compensatory processes (density-dependent mortality), with the plant's impact of larval entrainment likely being inconsequential. In 1996, plant impact was inconclusive; a number of storm events altered recruitment patterns at the termination of sampling. In 1997, recruitment success again appeared to be mediated by post-settlement, density-dependent processes of predation and/or resource competition, with power plant impact of less importance. A difference in habitat at one of the sites (Discharge) increased survival there, resulting in higher recruit densities at the Discharge reef by the end of the recruitment season. This work was not continued in 1998 because of the findings of minimal power plant impact.

Winter flounder

Larval winter flounder entrainment in 1997 and 1998 was inordinately high at PNPS. It is not clear whether an increase in the magnitude of entrainment of winter flounder larvae in 1997 and 1998 is representative of higher egg abundance, naturally high larval abundance (perhaps because of increased egg survival), or concentration of larval density resulting from the contribution of transport via the physical processes of on-shore winds and water currents, or by localized spawning events. Perhaps it is an amalgam of several of these factors. Entrainment mortalities of larvae at the present level are of great concern to MDMF. In the past, reduced operation of the circulating water pumps during the winter flounder spawning period resulted in substantially lower larval entrainment (Lawton et al. 1996).

We estimated adult winter flounder population size in 1998 at 264,812 individuals by an area swept approach (density extrapolation) using bottom trawl data. We had extended the study area in 1997 to include the recently estimated spatial range of the local population; however, much of the area is comprised of "untowable" bottom (i.e., rocky or otherwise unsuitable for trawling). As we are unable to sample within the entire bottom study area, we were not able to determine the mean density of winter flounder on hard bottom. We assumed it was the same as on trawlable bottom and calculated population abundance by expanding the average fish density over the entire study area. Entrainment in 1997 equated to a loss of 14.7% of the estimate of possible adults in the area, while in 1998 the loss was estimated to have almost doubled at 29.2%.

Mark-recapture data were used to address the question of population discreteness and to generate independent estimates of population size to corroborate with the density extrapolation estimate. The low number of winter flounder tag returns obtained through the present time has hampered especially the latter objective. Despite the low number of tag returns, there is evidence of a fairly high fidelity of the local population. Using the Capture mark-recapture model , the estimate of population size (fish $\geq$ 280 mm TL) in 1998 was 104,429 fish, with entrainment loss in equivalent adults being 74% of this absolute abundance estimate.

Atlantic silversides

In 1994, there were two acute incidents of impingement of Atlantic silversides at PNPS: 28-29 November - 5,800 fish and 26-28 December - 6,100 fish. In 1998, it was the dominant species and typically has led all other species in numbers impinged. No compensatory action has been taken because the silverside is a prolific, annual species with no commercial and only limited recreational value as bait. However, the silverside provides important forage for other piscivorous fish.

Alewife

A relatively high impingement of alewives occurred at PNPS on 8-9 September 1995 when an estimated 13,100 individuals died. The alewife is important as bait for the lobster fishery and for sportfishing, while its roe and flesh are used for human consumption. Employing a special publication of the American Fisheries Society (1992), we assessed the monetary value of this kill to be ca. $5,000.00. The MDMF negotiated with BECo for this sum of money which was granted for habitat rehabilitation (i.e., to help rebuild or repair a river herring fish ladder in the PKDB estuary situated on either the Jones River or Town Brook). Large impingements of alewives have been uncommon in recent years at PNPS, although it appears that the number of river herring has declined in the nearby Jones River run. Nevertheless, impingement monitoring should be continued at PNPS, so appropriate mitigative measures can be undertaken if warranted.

V. CONCLUSIONS

Rainbow Smelt

1. To compensate for rainbow smelt impingement at PNPS, MDMF formerly stocked smelt eggs into the Jones River but continues to work at improving spawning habitat. Restoration has been ongoing for the last five years.

2. After two years of egg stocking (ca. 1.8 million smelt eggs) into the Jones River, this effort had to be terminated because presently there is no good source of eggs for transplantation.

3. For the last four years, specially-designed egg collecting trays have been placed on the Jones River smelt spawning ground, which has resulted in an increased number of eggs being spawned on ideal substrate for egg survival. This work will continue into 1999.

4. Spawning tributaries should be inspected and cleared of any obstructions to fish passage each year before anadromous fish begin their spawning runs. The DMF has helped with the removal of several tree snags from the Jones River last year and would lend assistance in the future when necessary.

5. In general, we believe our smelt restoration efforts have been successful. We did move numbers of smelt eggs into the Jones River, and smelt have spawned over our collecting trays, with generally higher egg densities obtained on the artificial habitat. However, we have not measured hatching success and, thus, do not know how many eggs set on the trays survived to the larval stage. We also have not addressed subsequent larval survival or recruitment. On a positive note, the 1998 smelt run was the largest in over a decade. For the first time in several years, large numbers of adult smelt were observed on the spawning grounds during the daytime, and egg sets throughout the spawning ground were very good.

6. A decline in smelt populations has taken place throughout Massachusetts Bay and in Quebec, Canada, as well. Causality for the wide-spread declines is conjectural, although there are obvious environmental concerns, such as storm-water runoff, toxicants, nutrient loading, and sedimentation problems. These alterations degrade water and habitat quality and are likely linked to reduced smelt production. Future

remediation efforts in the Jones River and other local smelt spawning streams should stress water quality issues in the respective watershed. This should be a priority in the future restoration of smelt populations, and could include, for example, watershed runoff treatment and efforts to purchase a "green belt" along a spawning river or stream to prevent development or environmentally detrimental land use.

Winter Flounder

1. The nearby location of winter flounder spawning (retention) grounds, the relatively limited movement patterns of flounder north of Cape Cod, and the geographic bounds of the local population make this species especially sensitive to entrainment and impingement at PNPS.
2. In late summer, water temperatures in the immediate vicinity of PNPS's thermal discharge can exceed the avoidance temperature (24°C) for winter flounder which would exclude them from this relatively small (~ 4,047 m^2) area of stress.
3. The record 88.8 million winter flounder larvae entrained at PNPS in 1998 equated to an equivalent loss of 77,428 adult winter flounder from the local population. This level of entrainment should be of concern to the regulatory agencies.
4. In 1998, an estimated 1,493 winter flounder also were impinged at PNPS, with the majority being juveniles. Impingement of winter flounder at PNPS, as a source of mortality, is of lesser importance than entrainment effects.
5. Our tag recovery rate (4.0%) is low, being hampered by the sporadic reporting of tagged fish and the seasonal closure of the area to commercial fishing.
6. Our population estimate of winter flounder in the PNPS study area from post-stratified density extrapolation improved precision of the estimates, while estimates from mark-recapture models were hampered by the low tag recapture rates. The magnitude of entrainment impact of PNPS on winter

flounder has been estimated by various methods. Estimated impacts the last two years are of concern, and mitigation measures should be undertaken at the plant site and restoration measures (to be determined) conducted in the essential fish habitat of the surrounding waters.

VI. ACKNOWLEDGEMENTS

The authors thank Wayne and Dana Bassett of Canal Marine Fisheries, Inc. for donating the bait used during cunner trapping. Thomas Hoopes of MDMF produced the GIS map of flounder recapture areas. Robert Dylan and Jack Sullivan of Boston Edison Company collected sportfish data at Pilgrim Shorefront. Al Hardy and his Agricultural Engineering class at Silver Lake Regional High School provided the labor to keep the Jones River smelt run obstruction free. Dave and Carole Arnold provided their vessel, *Frances Elizabeth,* which was used for the tagging of winter flounder, while Jeff Good provided his vessel, *Alosa,* for winter flounder recapture operations. Gary White from Colorado State University assisted with technical expertise regarding population estimation using the MARK and CAPTURE tag recapture programs for winter flounder data. We appreciate the guidance of Robert D. Anderson of BECo, W. Leigh Bridges of our Division, and members of the Pilgrim Administrative-Technical Committee for their input on various studies and editorial comments on project reports and papers.

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FINAL
SEMI-ANNUAL REPORT
Number 53

BENTHIC ALGAL MONITORING AT THE PILGRIM NUCLEAR POWER STATION (QUALITATIVE TRANSECT SURVEYS)

January-December 1998

to

BOSTON EDISON COMPANY
Regulatory Affairs Department
Pilgrim Nuclear Power Station
Plymouth, Massachusetts 02360

From

ENSR
89 Water Street
Woods Hole, MA 02543
(508) 457-7900

1 April 1999

6 Meetings

The project and/or data manager will attend full Administrative-Technical Committee and Benthic Subcommittee meetings when appropriate. This will help ensure communication between ENSR, the field team, and the A-T Committee so that the quality of the benthic survey will be maintained as guided by the Committee.

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EXECUTIVE SUMMARY

This report presents results of qualitative surveys of benthic algae performed in 1998 in the area of thermal effluent from the Pilgrim Nuclear Power Station (PNPS). The report summarizes the impact of the PNPS on algal distributions near the discharge canal. At the request of the Pilgrim Administrative-Technical Committee (PATC) Benthic Subcommittee, three field surveys were planned for 1998. These field studies were conducted in March, June, and October and included transect surveys designed to map algal cover in the area of water outflow. These investigations constitute the most recent phase of long-term monitoring of thermal effluent effects on the benthic algal community within and just offshore of the PNPS discharge canal. Field survey techniques were identical to those used in prior years. Starting in 1996, data from each seasonal survey were compared to the historical baseline (maximum measurements recorded prior to the 1996 survey year) for that season. Measurements greater than 15% above the historical baseline trigger a report to the (PATC) Benthic Subcommittee for review.

The qualitative transect studies performed to evaluate the *Chondrus crispus* (Irish moss) community indicate that from October 1995 through March 1998 (with the exception of December 1996) the sizes of the denuded and totally affected areas in the thermal plume were larger for each season surveyed than in earlier surveys when the power plant was in full or nearly full operation (1983, 1985, 1989-1995). In 1998 the denuded and totally affected areas measured in March were only slightly larger than the historical spring maxima, while in June they were well within those seen in the earlier surveys. Although the *Chondrus* denuded and totally affected zones were much larger than historical maxima in the fall survey, they were much reduced in size compared to those seen in the fall of 1997. A dense cohort of newly settled blue mussels (*Mytilus edulis*) was already in place by March 2 and covered a yet larger area by June. Dense congregations of mussels were still present over much of the affected area in late October even extending beyond the sparse and stunted *Chondrus* zones.

The annual capacity factor at PNPS for 1998 was 97.1%, higher than in any previous year. In comparison to 1996, the year with the second highest MDC (90.5%), the *Chondrus* denuded and totally affected zones in March and June were smaller but by the time of the fall survey were larger than in 1996. However, none of the 1998 areal measurements, excepting an insignificantly larger totally affected zone in the spring of 1998, were as large as those in the comparable 1997 season. The *Chondrus* denuded and totally affected zones surveyed in the outfall area in 1998 seem to have rebounded from the anomalously large expanses measured in 1997, reinforcing the idea that the dredging operation that took place during the summer of 1997 may have had a noticeable impact on the affected *Chondrus* zones.

1.0 INTRODUCTION

The presence of hundreds of square meters of seafloor where the regionally abundant red alga, *Chondrus crispus*, is unnaturally absent, even in the presence of suitable substrata, provides evidence that the PNPS nearfield discharge area is affected by elevated temperature and high current velocity, causing bottom scouring, of the cooling water outflow. To study this acutely impacted area, a qualitative diver transect study was designed to map the effects of the thermal effluent on nearby algal distributions. SCUBA divers perform seasonal transect surveys to measure the extent of denudation and other reductions in size or density of the algal flora, particularly *Chondrus crispus*, in the nearfield discharge area.

This report represents a continuation of long-term (25 yr) benthic studies at (PNPS) designed to monitor the effects of the thermal effluent. The 1998 monitoring program consisted of three qualitative underwater surveys of algal cover in the nearfield thermal plume of the effluent within and beyond the discharge canal (Figure 1), performed in March, June, and October. Currently, no quantitative assessments of benthic flora or fauna are being made. Beginning in 1996, reports have been prepared after each seasonal survey to compare the collected data with an historical baseline that tabulates, for each parameter, the maximal sizes measured prior to the 1996 survey season (1983 through February 1996). This Semi-Annual Report includes seasonal qualitative observations, tabular and graphical comparison of these data with historical baselines, and a summary of the potential impact on algal distributions caused by PNPS. Work was performed under Boston Edison Co. (BECo) Purchase Order LSP009647 in accordance with requirements of the PNPS NPDES Permit No. MA 0003557.

PNPS is a base-load, nuclear-powered electrical generating unit designed to produce 670 megawatts of electrical energy when operating at full capacity. The condenser is cooled by water withdrawn from Cape Cod Bay and subsequently returned to the Bay via an open discharge canal designed to dissipate heat through rapid mixing and dilution of the outflowing water. Two circulating water pumps produce a maximum water flow of approximately 20 $m^3 s^{-1}$. The PNPS cooling system may affect the benthic community in three ways: 1) by warming ambient waters ($\Delta T=18°C$), 2) through chemical discharge (mainly Cl_2), and 3) by seabed scouring from the rapid (~ 2.1 mps at low tide) flow regime. High temperature and chemical discharges may stress the algal community so that species composition and community structure change, with the extent of such change depending upon season and local oceanographic conditions. A high current velocity directly affects the benthos by actually removing benthic organisms and inhibiting settlement and recolonization; where there is intense bottom scouring, rock surfaces may support fewer and smaller macroscopic organisms than normally would be present.

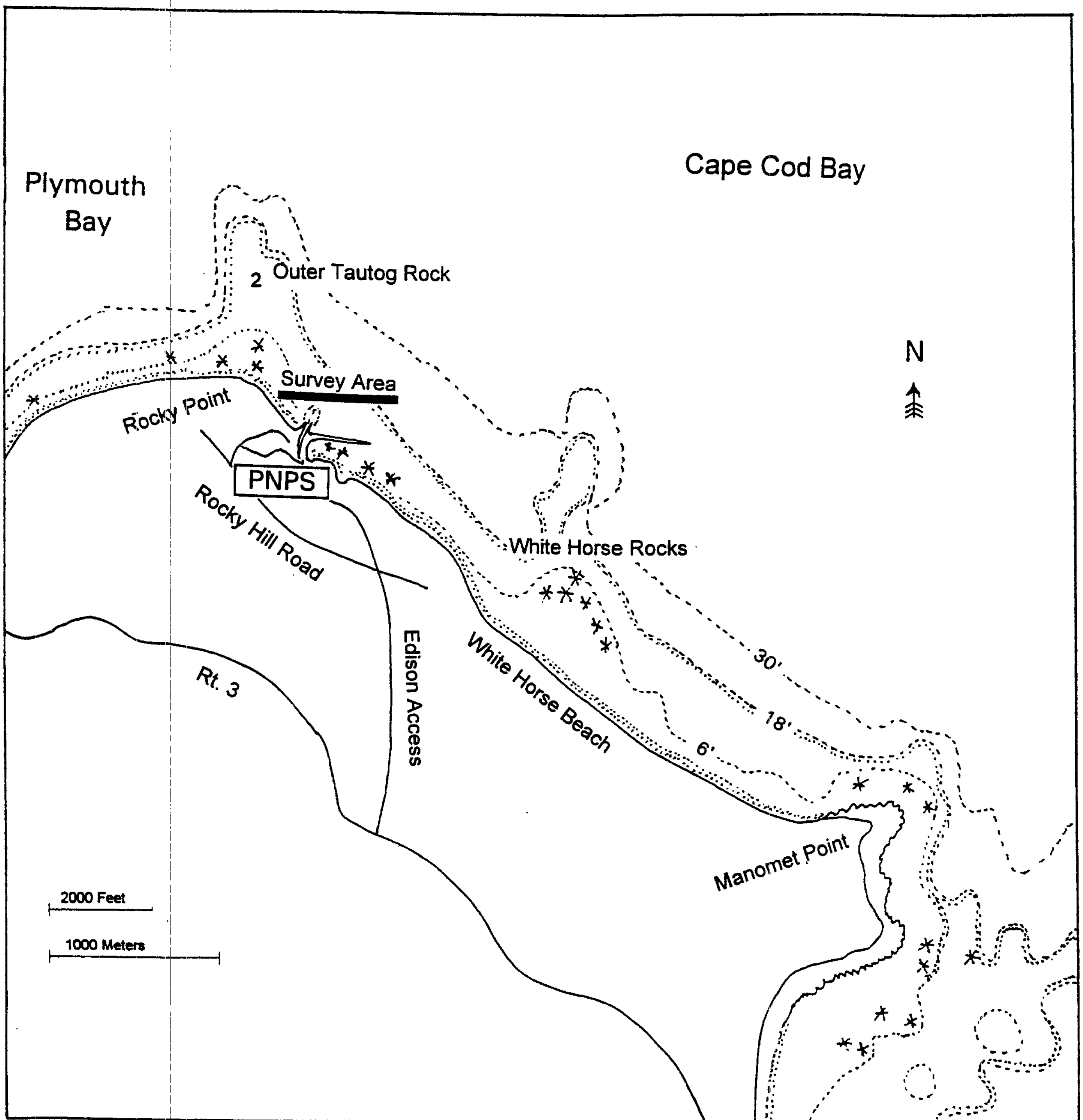

Figure 1. **Location of Pilgrim Nuclear Power Station Qualitative Algal Survey Area.**

2.0 FIELD STUDIES

2.1 METHODS

The qualitative algal survey is performed by SCUBA divers in the same location and with the same techniques that have been used since the present monitoring program began, approximately 17 years ago. The effluent area is surveyed by two or three SCUBA-equipped biologists operating from a small boat. For all 1998 surveys, the divers were able to launch their boat from the fishermen's launching site within the PNPS facility. For the qualitative transect survey, underwater visual observations are made along the axis of the discharge canal. A line is stretched across the mouth of the discharge canal (Figure 2). A weighted central transect line (CTL), marked at 10-m intervals, is then attached to the center of this line and deployed along the central axis of the canal to a distance of 100 m offshore, where it is anchored. Using a compass, divers extend a measuring line at least 45-m long and marked at 1-m intervals, perpendicular to the CTL at each 10-m mark. A diver swims along this third line, recording changes in algal cover from the CTL through the denuded, sparse, and stunted *Chondrus* areas, until the algal cover looks normal. A large boulder, nearly exposed at mean low water, is used as a landmark by dive teams and serves as a visual fix for proper alignment of the CTL. To ensure consistency among surveys, the divers make sure that the boulder is always located at 65 m along and just to the north of the CTL.

The terminology established by Taxon (1982) and followed in subsequent years uses the general abundance and growth morphology of *Chondrus crispus* to distinguish between "denuded" and "stunted" zones. The **denuded zone** is the area in which *Chondrus* occurs sparingly and only as stunted plants restricted to the sides and crevices of rocks. In this area, *Chondrus* is found on the upper surfaces of rocks only where the microtopography of the rock surfaces creates small protected habitats. In the **stunted zone**, *Chondrus* is found on the upper surfaces of rocks but is noticeably inferior in height, density, and frond development compared to plants growing in unaffected areas. In 1991 the divers began to discriminate between a stunted zone and a "sparse" zone. The **sparse zone** is an area with normal-looking *Chondrus* plants occurring only at very low densities. The **control zone** begins at the point where *Chondrus* height and density are fully developed. The dive team must keep in mind while taking measurements that the shallow depths northwest of the discharge canal hamper normal *Chondrus* growth. In addition to evaluating extent and condition of algal cover, the divers record any unusual recent events in the area, such as the occurrence of unusually strong storms, and note the location of any distinctive algal or faunal associations.

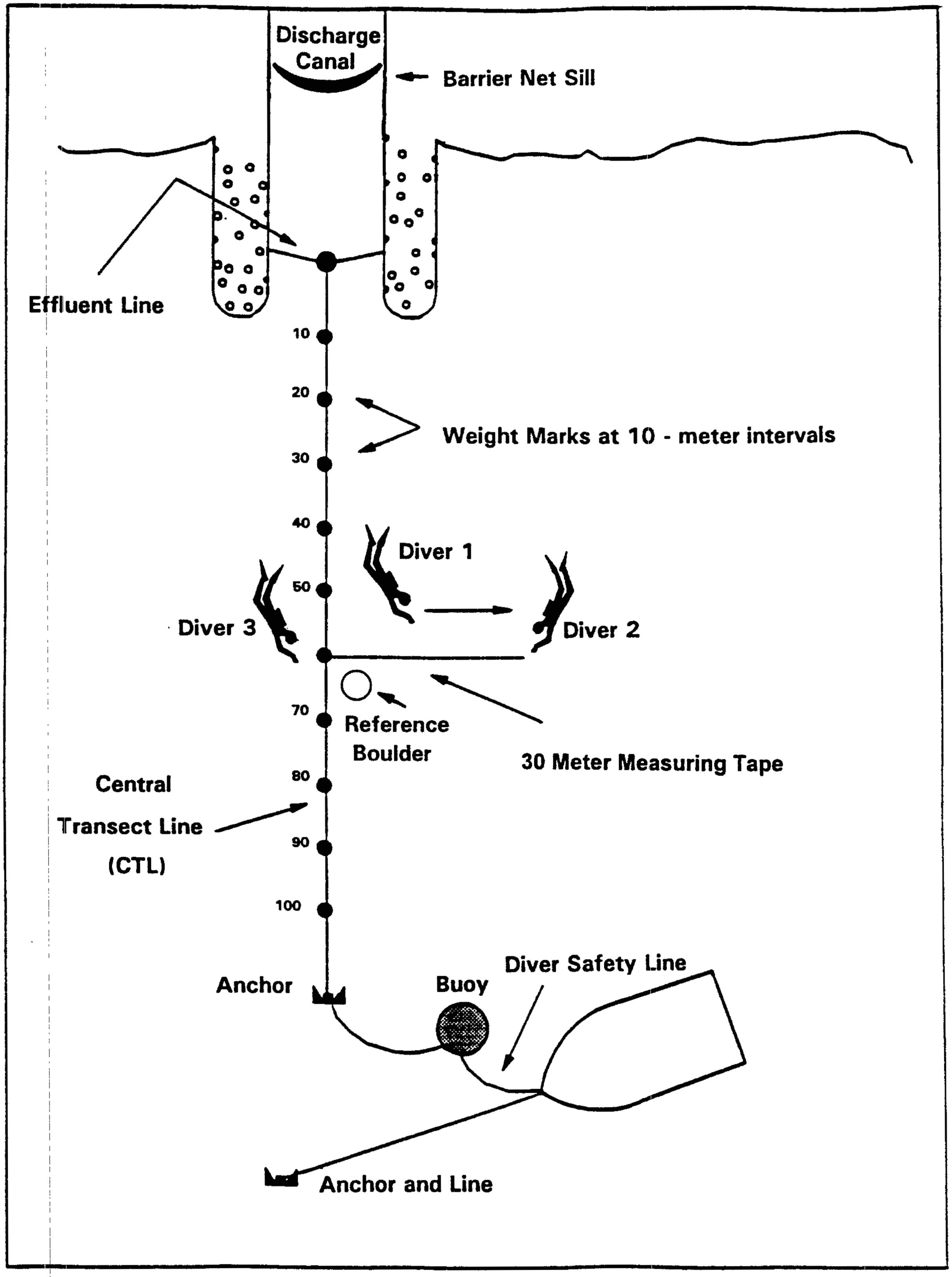

Figure 2. Design of the Qualitative Transect Survey.

Since the April 1996 survey, Quarterly Progress reports have been submitted to BECo. These reports tabulate areal results of each SCUBA survey and compare them to previously measured maximal sizes of *Chondrus* denuded and totally affected zones, as well as other parameters, for that season. Particular attention is paid to changes in the sizes of impacted regions that exceed earlier results (prior to 19960 by more than 15%, in which case a written report is to be submitted to the PATC Benthic Subcommittee. Table 1 and Figure 3 summarize these comparisons for 1998. The quality control (QC) protocol for the 1998 benthic algal monitoring program is included as Appendix A.

2.2 RESULTS

Qualitative transect surveys of acute nearfield impact zones began in January 1980 and were conducted quarterly since 1983 through 1997. This frequency was reduced to three surveys for 1998 that were performed on March 2, June 11, and October 28, bringing the total number of surveys conducted 72. Results of surveys conducted from January 1980 to June 1983 were reviewed in Semi-Annual Report 22 to BECo (BECo, 1983). A summary of surveys conducted between 1983 and 1997, including a review of the four performed in 1996, was presented in Semi-Annual Report No. 51 (BECo, 1998). The present report summarizes the March and June 1998 surveys, presents detailed results of the October 1998 survey, and discusses long-term trends.

Figures 4 - 7 show the results of the 1998 transect surveys. in the figures, the denuded zone is essentially devoid of *Chondrus crispus*, while sparse zones have normal looking *Chondrus* that is sparsely distributed and stunted zones contain smaller than normal *Chondrus* plants. Dislodged jetty boulders encountered by the divers along their transects are indicated. The landmark boulder (at 65-m) is plotted in all figures as are positions of other common algal and faunal species observed. A large area, densely covered by juvenile mussels, was observed during each survey and delineated.

2.2.1 MARCH 1998 TRANSECT SURVEY

The denuded and sparse *Chondrus* zones observed on March 2, 1998, immediately offshore of PNPS, are shown in Figure 4. The denuded area (1437 m^2) was 23% smaller than in spring 1996 and 14% smaller than in March 1997 but was still larger than measured during all other previous spring surveys. The totally affected area (2112 m^2) was 40% smaller than it had been during the previous survey in December 1997, 1% larger than in the 1997 spring survey, and 4% larger than measured in April 1983, the historical spring baseline for the total affected zone (Table 1). The denuded region extended 93 m offshore along the CTL and, as often seen before, was asymmetrically distributed with 56% of the denuded area north of the line.

Table 1. **Qualitative Algal Survey Data for 1998 Compared to Historical Baseline Data.**

	Spring			Summer			Fall		
Measurement	March 1998	Historical Baseline (Date)	Percent Change from Baseline	June 1998	Historical Baseline (Date)	Percent Change from Baseline	Oct. 1998	Historical Baseline (Date)	Percent Change from Baseline
Total Denuded Area (m^2)	1437	1321 (3/91)	+8%	1738	1835 (6/90)	-5%	2469	2043 (10/95)	+21%
Total Affected Area (m^2)	2112	2029 (4/83)	+4%	2136	2135 (6/90)	+0%	3112	2348 (10/95)	+33%
Maximal Distance of Affected Area from Discharge Canal (m)	93	94 (3/91)	-1%	92	105 (6/92)	-12%	100	100 (9/90; 10/95)	+0%
Maximal Width of Affected Area (m)	34	40 (4/83; 3/84)	-15%	42	39 (6/84)	+8%	54	42 (10/94)	+29%

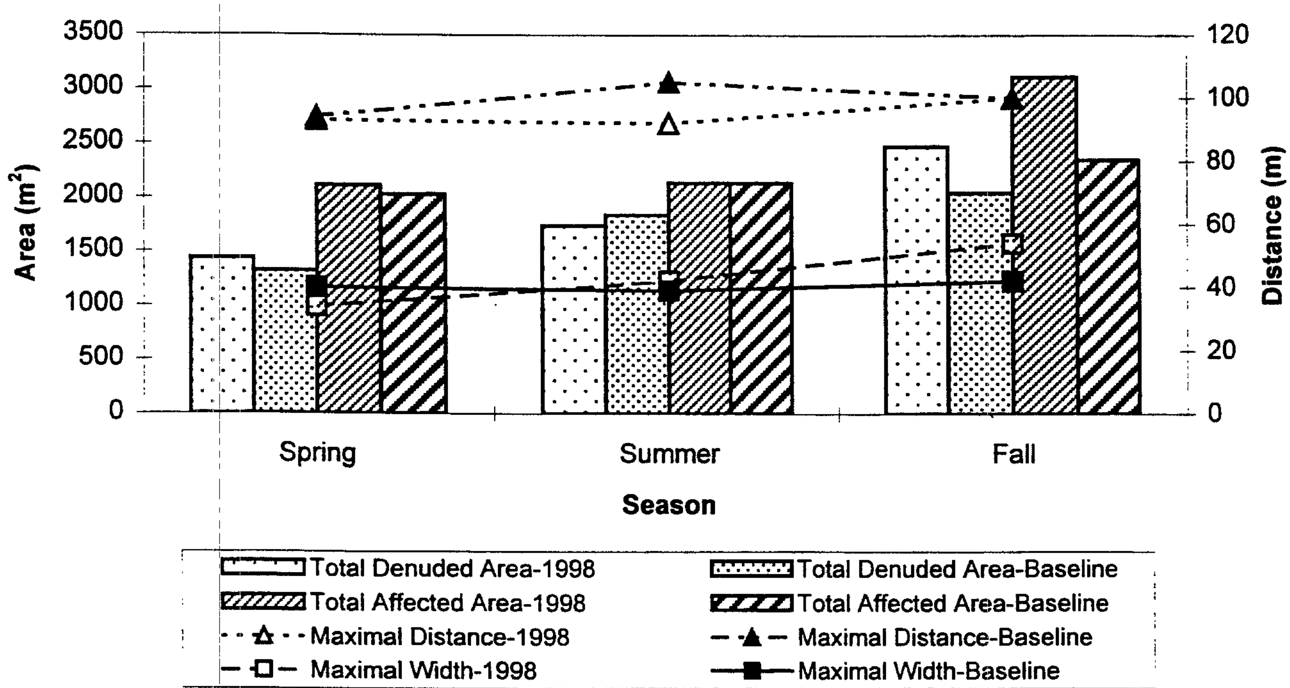

Figure 3. **Qualitative Algal Survey Data for 1998 Compared to Historical Baseline Data.**

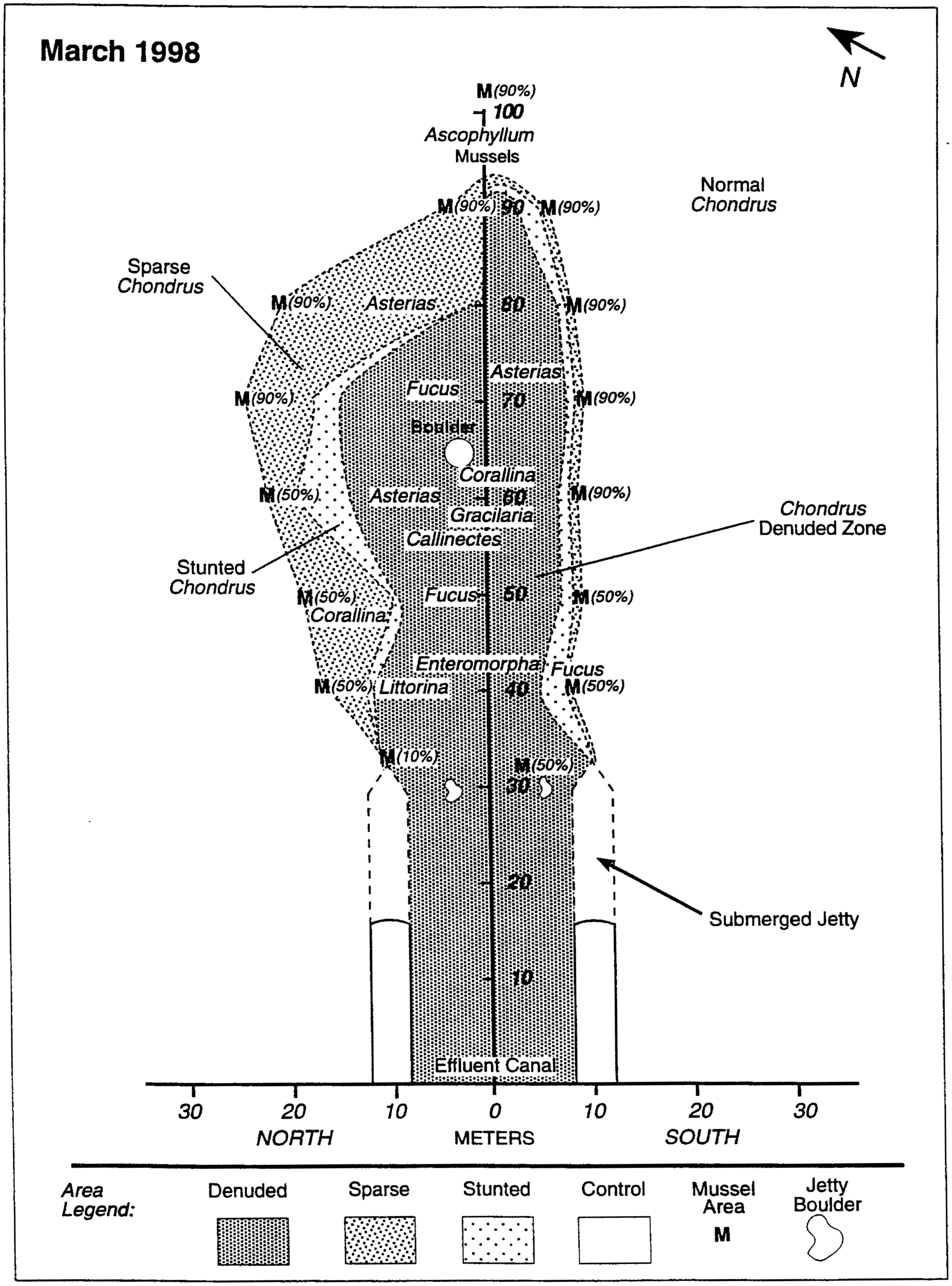

Figure 4. **Denuded, Sparse, and Stunted *Chondrus* Zones and Dense Mussel Area Observed in March 1998.**

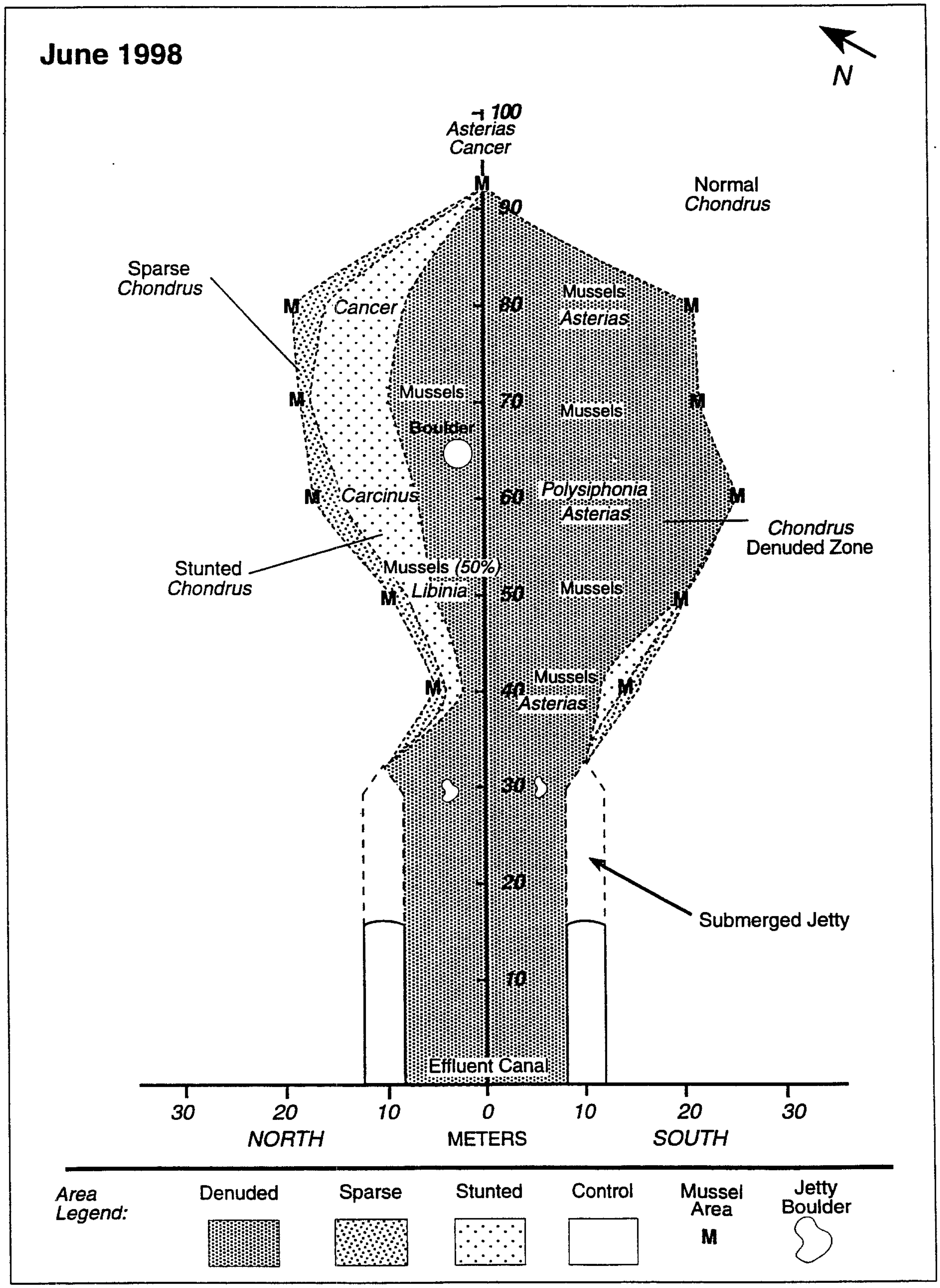

Figure 5. **Denuded, Sparse, and Stunted *Chondrus* Zones and Dense Mussel Area Observed in June 1998.**

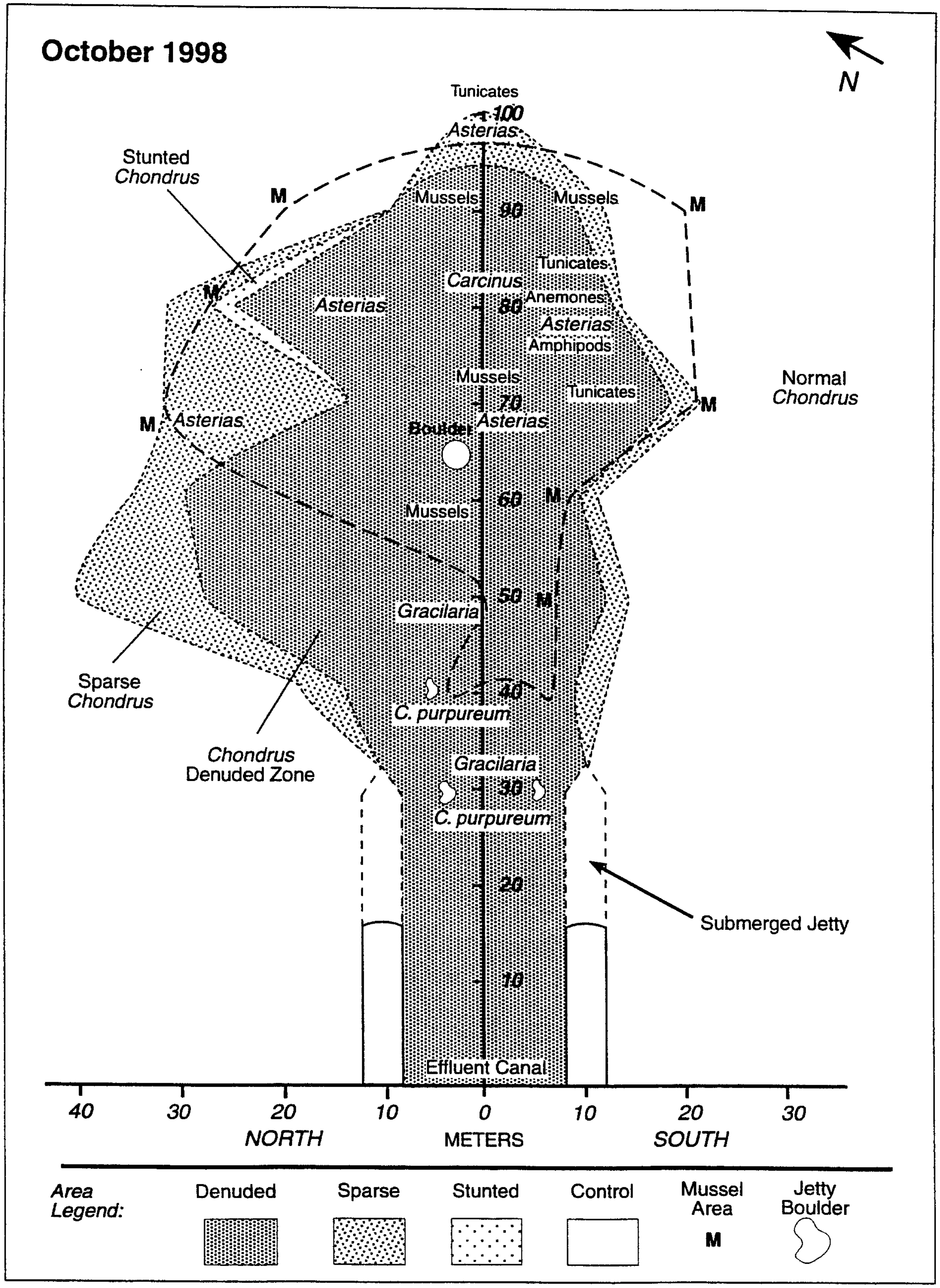

Figure 6. **Denuded, Sparse, and Stunted *Chondrus* Zones and Dense Mussel Area Observed in October 1998.**

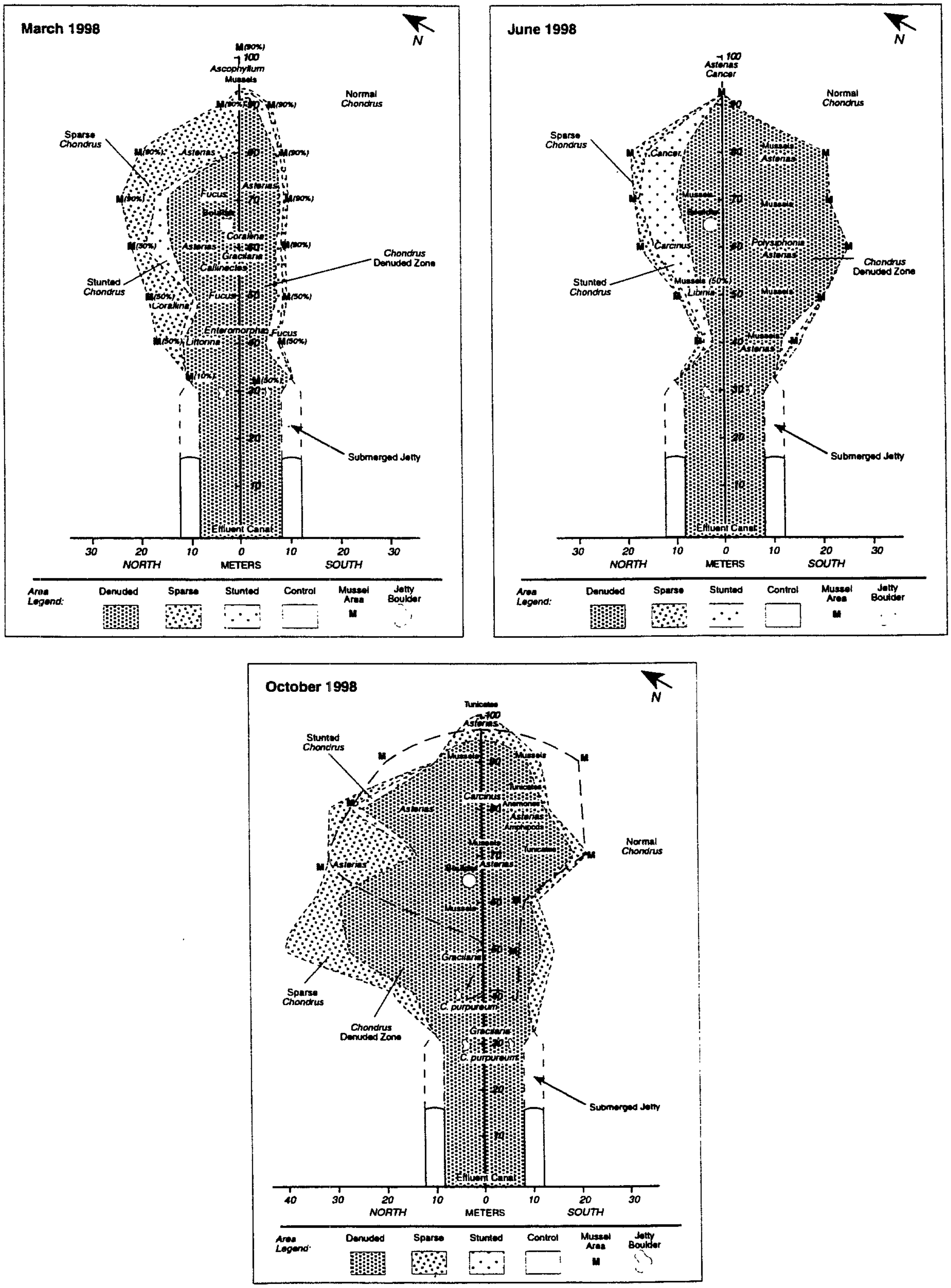

Figure 7. **Results of the 1998 Qualitative Transect Surveys of the PNPS Acute Impact Zone off the Discharge Canal taken in March, June, and October 1998.**

Other algae present included: *Enteromorpha*, *Fucus*, *Corallina* and, further offshore, *Ascophyllum*. In contrast to 1997, an extensive set of the blue mussel, *Mytilus edulis*, had already occurred, a phenomenon perhaps accelerated by our anomalously warm winter. Juvenile mussels, 1-5 mm in length, were common (outlined by **M**'s in Figure 4) and responsible for the almost complete epiphytization of *Chondrus*. Other invertebrates included: many Asterias forbesii, a mussel predator; *Littorina littorea*, the common periwinkle; one blue crab, *Callinectes sapidus*; and the colonial anemone, *Epizoanthus incrustatus*. No fish or lobsters were seen.

2.2.2 JUNE 1998 TRANSECT SURVEY

Results of the divers' survey for June 11, 1998 are mapped in Figure 5. The *Chondrus* denuded zone and totally affected areas were smaller this summer than observed during the past two summer surveys. The denuded zone (1738 m^2) extended 92 m offshore along the CTL, was 21% larger than three months earlier in March, 31% smaller than in June 1997 and 5% less than the June 1990 summer historical baseline of 1835 m^2 (Table 1). In contrast to the pattern seen during most prior surveys, the denuded zone extended much farther to the south than usual with three-quarters of the denuded zone south of the CTL.. The sparse and stunted *Chondrus* zone (398 m^2) was 41% smaller than in March 1998 and 73% smaller than in the previous June. The total affected area (2136 m^2) was only 1% larger than in March 1998, nearly half the size as measured the previous June, and the same size as the 1990 historical summer baseline (2135 m^2). Very few algal plants were seen. Mussels carpeted the area so thickly than even identification of *Chondrus* plants could be verified only after the mussels were removed. The region with 100% mussel coverage (outlined by **M**'s in Figure 5) was very nearly coincident with the totally affected *Chondrus* area. Dense aggregations of juvenile (5-10 cm in diameter) starfish, *Asterias forbesii* were seen. Other invertebrates present included: rock crabs (*Cancer borealis*), green crabs (*Carcinus maenas*), and spider crabs (*Libinia* sp.). Winter flounder (*Pseudopleuronectes americanus*) and a school of striped bass (*Morone saxatilis*) were seen.

2.2.3 OCTOBER 1998 TRANSECT SURVEY

Figure 6 shows the results of the transect survey conducted on October 28, 1998. For most parameters, the 1998 measurements exceeded the 15% target limit (Table 1). However, the surveyed areas were not as large as measured during the 1997 fall survey and the divers were able to inspect the entire area. The area of the denuded zone (2469 m^2) was much larger (42%) than in June 1998, a not unusual event, and 21% larger than the October 1995 baseline. The pattern of denudation had reverted to the more usual situation, with most of the affected area (two-thirds) north of the CTL, thus, reversing the unusual pattern seen in June.

The areas of the sparse and stunted *Chondrus* zones totaled 643 m^2 in October, smaller than in the fall of 1997 but approximately the same as seen in the fall 1996 (636 m^2). The total affected area in October was 3112 m^2, 10% larger than measured in June 1998, and 33% larger than the historical baseline (2348 m^2) established in October 1995. The totally affected area extended out along the CTL to 100 m (the same as the baseline); the maximal width of the affected zone was 54 m at the 50-m mark on the CTL (29% larger than the baseline). Besides *Chondrus* the only other macroalgae noted were *C. purpureum* and *Gracilaria* spp. growing close to the CTL out to the 60-m mark.

Mussels had disappeared from the portion of the CTL closest to the jetties, but were present in a narrow band along the CTL between the 40-m and 50-m marks, and abundant (20 cm in length) in a wide area even extending beyond the *Chondrus* affected zone from the 70-m to 95-m marks on the CTL (outlined by **M**'s in Figure 6). The most unusual invertebrates seen were a number of the colonial tunicates, *Diplosoma* spp. This is an invading species and has been noticed for about the last two years on the pilings of the WHOI dock in Woods Hole. A few specimens had been seen in the BECO dive area on earlier occasions but the numbers present in October were much greater especially from the 70-m to 100-m marks on the CTL. Other invertebrates observed included: starfish, amphipods, green and rock crabs, and anemones. No fish or kelp were seen.

2.3 DISCUSSION

The configuration of the *Chondrus crispus* denuded zone, that can extend seaward even farther than 100 m beyond the discharge canal, is readily apparent to SCUBA divers and easily mapped from the qualitative transect survey. Stunted and sparse zones are sometimes less obvious, but the sparse zones observed in 1998 were delineated without difficulty. For the March 1998 survey, the sizes of the denuded and totally affected zones were slightly larger than the historical maxima (+8% and +4%, respectively), while in June, both areal measurements fell well within those surveyed when the plant was in full or nearly full operation and within the 15% target limit when compared to the historical baseline (maximum measurements recorded prior to the 1996 survey year). For the October 1998 survey, the areas of the denuded and total affected zones were much smaller than in the fall of 1997 but still large compared to the baseline. The denuded zone was the third highest ever measured (after the 1997 summer and fall surveys) and the totally affected area was the second largest measured during a fall survey when the plant was in full or nearly full operation. By March 1998, an extremely dense mussel mat was already present, much earlier in the year than in most earlier surveys. By June, this mat, composed of juvenile mussels 5 to 30 mm in length, provided nearly 100% coverage over the entire *Chondrus* affected region. This mussel mat phenomenon has been seen during every June survey since 1990, except for 1991. The areas of the denuded and totally affected zones were again greater in June than in March, the usual trend when early summer growth of *Chondrus* is adversely affected by high mussel settlement. In October 1998, even though the mussel mat was somewhat reduced in size, the denuded and totally affected *Chondrus* areas were still very large, exceeding the historical baseline by 21% and 33%, respectively.

The highest ever annual capacity factor at PNPS for 1998 (97.1%), coupled with summer temperatures, probably was reflected in the size increase of the *Chondrus* affected zones seen in October over those measured in June. The decrease in the June and October 1998 areal measurements when compared to those delineated in the same seasons in 1997 may reflect a recovery from the additional stress placed on the system last year from the summer-time dredging operation that took place in the plant intake area in 1997.

3.0 HISTORICAL IMPACT OF EFFLUENT DISCHARGE AT PNPS ON ALGAL DISTRIBUTION

3.1 BACKGROUND

Historically, operational conditions at the PNPS have provided opportunities to assess long-term trends associated with impacts on the benthic community. Plant operations have included consecutive years of high operation as well as times when there were complete shutdowns, sometimes for prolonged periods. The longest outage in the history of the plant began in April 1986 and continued until March 1989. During this period the benthic community associated with the effluent canal and nearby areas immediately offshore experienced reduced current velocity as the use of circulating pumps was restricted to one or none (Figure 8). In addition, the discharge water remained at ambient temperature. As a consequence, the benthic community normally affected by these effluent parameters recovered, so that by 1988 there was essentially no difference between the control stations and the areas near the discharge canal.

Studies conducted after the power plant resumed electrical generation at full operating capacity, with the consequent thermal discharge and consistent use of one or both circulating pumps, assessed the impact of plant operation on a benthic environment that had returned to near ambient conditions. Quantitative faunal and algal monitoring studies, and qualitative transect surveys were conducted through 1991. In 1992, community studies of the benthic algae and fauna were discontinued. From 1992 through 1997, the monitoring program consisted of quarterly qualitative surveys of the discharge area. For 1998, three seasonal (spring, summer, and fall) qualitative surveys were performed.

PNPS operated at it's highest ever capacity in 1998. Figure 8 shows the monthly dependable capacity (MDC) factor and circulating water pump operation of PNPS since 1983. The percent MDC is a measure of reactor output and can be used to estimate thermal loading to the marine environment. A maximum MDC value of 100% approximates, with some seasonal variation, the greatest allowable increase (18°CΔT) in ambient temperature for effluent water discharged to Cape Cod Bay. In 1998, the monthly dependable capacity factor was greater than 97.0 % for 8 months and never less than 92.5%.

3.2 QUALITATIVE TRANSECT SURVEYS: 1983-1998

Results of the qualitative transect surveys from 1983 through 1998 are summarized in Figure 9. The total acute impacted area (denuded, sparse, and stunted), the area of the denuded zone only, and the monthly PNPS capacity factor (MDC) are plotted. The difference between the denuded and total acute impact zones represents the area of the sparse and stunted zones.

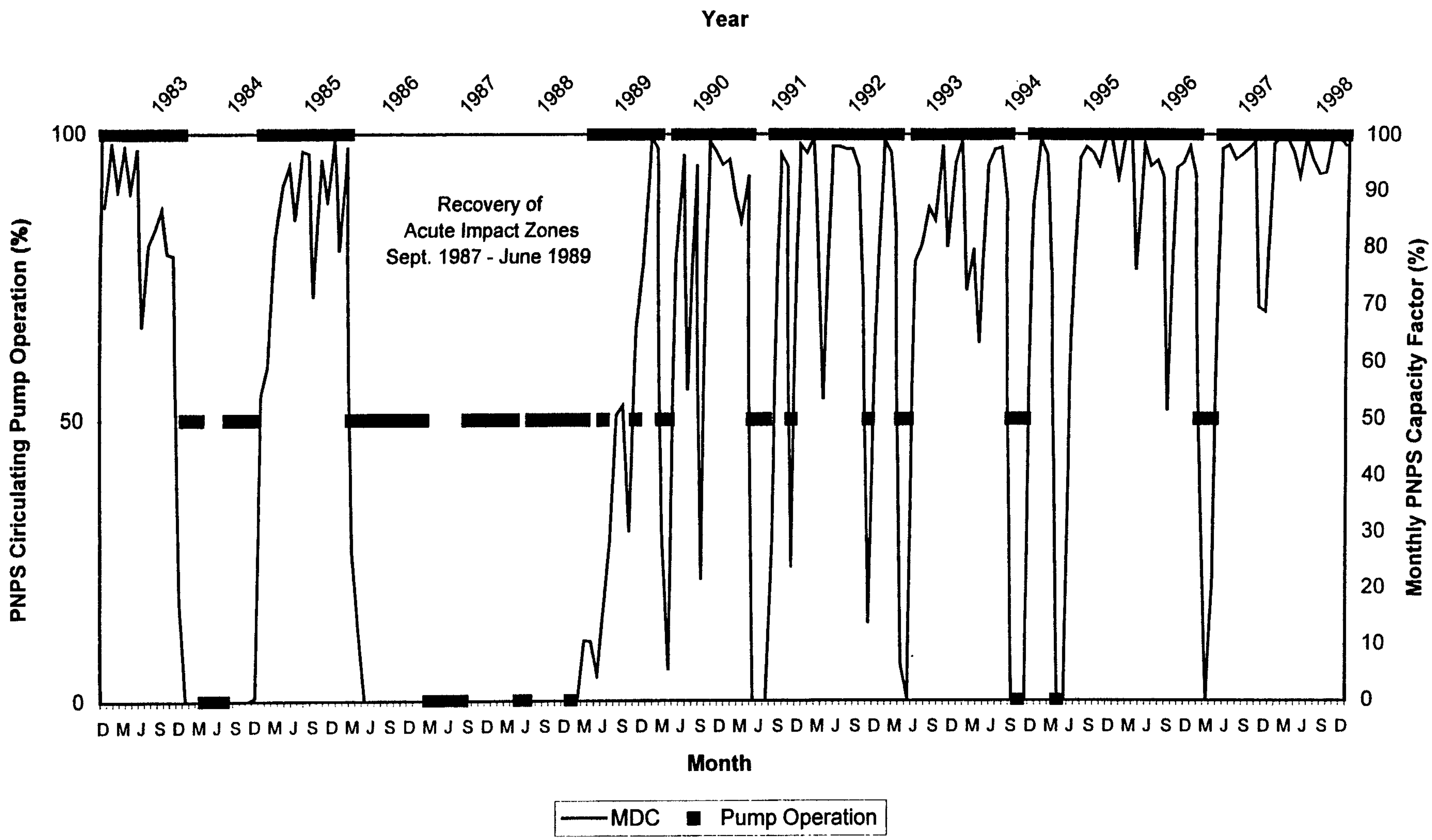

Figure 8. Monthly PNPS Capacity Factor (solid lines) and Circulating Pump Activity (black bars at 100% = 2 pumps; at 50% = 1 pump; at 0% = 0 pumps) Plotted for the Period 1983 Through December 1998.

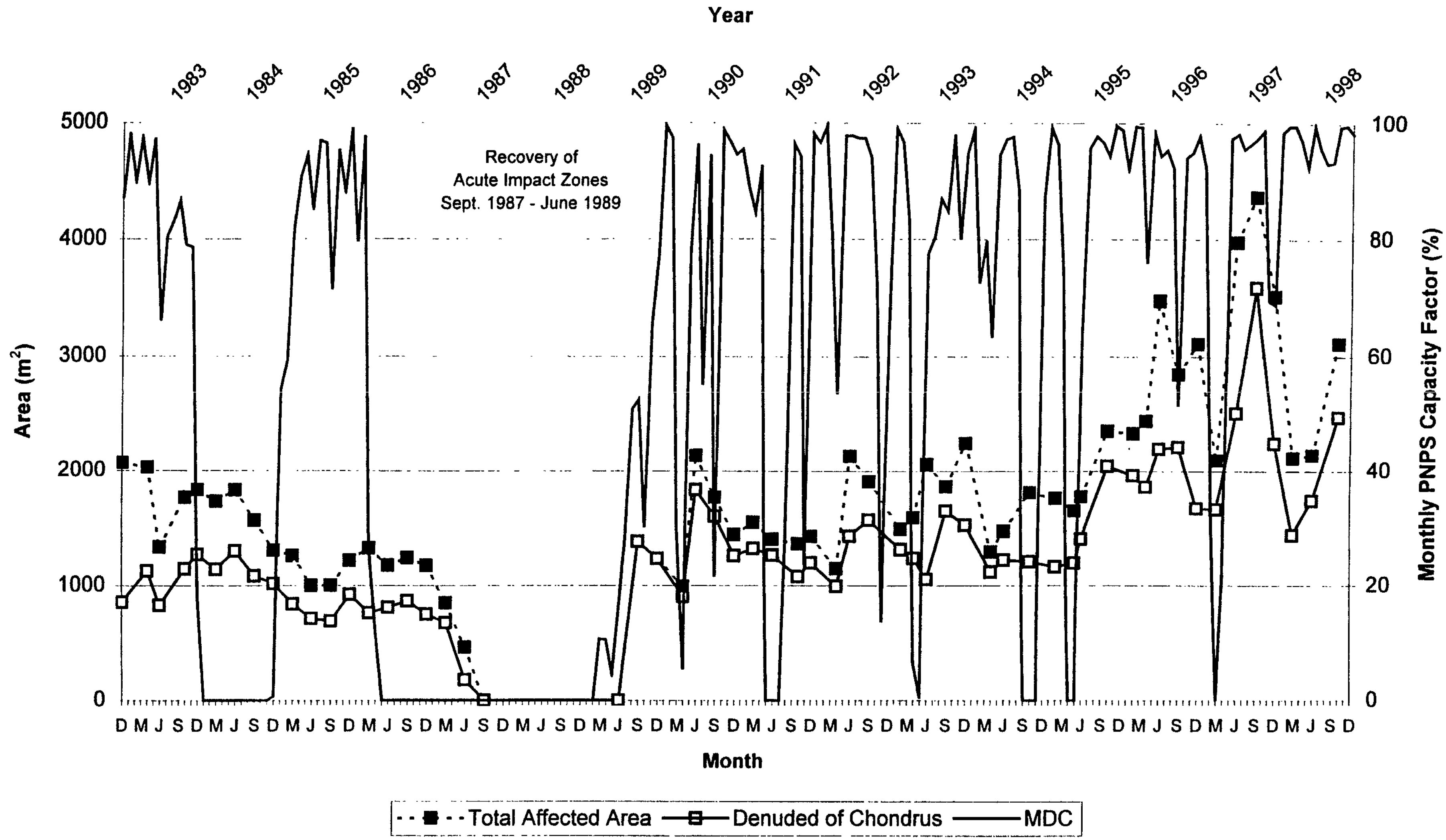

Figure 9. **Area of the Denuded and Totally Affected Zones in the Vicinity of the PNPS Effluent Canal Plotted with the Monthly PNPS Capacity Factor (MDC) for the Period 1983 Through 1998. No area measurements were made from September 1987 through June 1989 because definitive demarcations of denuded and stunted zones were absent.**

A lag in recovery time in the acute impact zone during and following the 1984 PNPS power outage was reported in Semi-Annual Report No. 27 (BECo, 1986). Evidence of this slow recovery included a decrease in the area of the total acute impact zone that began in mid-1984 (5 months after the cessation of power plant operations) and continued through mid-1985. Between December 1984 and December 1985, the total affected area was the smallest recorded between 1983 and 1986, indicating a delay in recovery in response to the absence of thermal discharge and reduced circulating water pump operation in 1984. This delay phenomenon also held true when the situation was reversed, so that the size of the acute impact zone began to increase only 6 to 9 months (September to December 1985) after the resumption of thermal effluent discharge and normal circulating water pump operation. These results confirmed a delay of 6-9 months between the causal factors (cessation or resumption of thermal effluent discharge and normal pump operation) and associated responses (decrease or increase in size of the acute impact zone). In 1987, in response to the 1986-1989 outage, increased recolonization of the denuded and stunted zones by *Chondrus* made zone boundaries difficult to distinguish (no areal differences could be discerned from September 1987 through June 1989). As in summer 1984, the large size reduction of the denuded zone between December 1986 and June 1987 was primarily the result of the shutdown of the circulating water pumps in late February 1987 that continued into the summer (BECo, 1988). Apparently, water current scouring is a greater stress to algal colonization than elevated water temperature. Generally, scouring denudes the substratum, whereas elevated temperature results in stunted growth (Bridges and Anderson, 1984).

In 1988, low circulating water pump activity caused few scouring effects. The 1988 transect surveys showed such an increase in recolonization of formerly denuded and stunted zones by *Chondrus*, because of the continuing outage, that divers could not detect zonal boundaries or make area measurements. In March and June 1989, divers were still unable to detect boundaries of denuded or stunted zones (BECo, 1990). In September and December 1989, presumably in response to increased PNPS operations with resultant thermal effects and scouring of the acute impact zone, boundaries began to be redefined and area measurements were made of the total impact zone.

During 1990, boundaries between the stunted and denuded zones became even more clearly defined and areal measurements of both zones were made. The denuded and total impact zones in June 1990 were the largest measured since 1983 (BECo, 1991). The dramatic increase in total affected area that occurred between April and June 1990 had not been seen before. The typical pattern seen prior to 1990 was that during spring, with warmer temperatures and increased sunlight, algal growth flourishes, and the impact area declines even in years when the power plant is operating at high capacity. The pattern in 1990 appeared anomalous until, more recently, a correlation was made between the appearance of enormous numbers of juvenile mussels and the occurrence of large denuded and total affected zones. The divers noted remarkable numbers of juvenile mussels during the June 1990 dive. Thus, it would appear that the large affected zones result, at least partly, from damage suffered by the *Chondrus* plants due to the massive settlement of mussels.

In 1991, the boundaries of the acute impact zone remained well-defined, except that in June there was no true stunted zone but only an area described by the divers as "sparse", that is, where the algal plants grew normally but were thinly distributed. From March to June, the total affected area and the *Chondrus* denuded zone decreased in area, a return to the typical pattern seen before 1990 (BECo, 1992). This decrease in area continued through the October survey, perhaps aided by the power plant outage from May into August. There was a slight increase in the affected area in December.

During 1992, the divers were unable to discern a *Chondrus* stunted region. Except for June, they noted zones containing normal but sparsely distributed *Chondrus* plants. An enormous set of mussels that had reached 0.5 cm in length by June, totally obliterated the boundary between the denuded and sparse areas. Parallel to results seen in 1990, the areas of the denuded and total acute impact zones in June 1992 were larger than any seen (except for 1990) since 1983, and the dramatic increase in total affected area that occurred between April and June 1990 occurred once again in 1992. Thus, the pattern seen in 1990 can no longer be considered anomalous but may be related to oceanographic conditions that lead to a large settlement of mussel larvae and consequent damage to *Chondrus* plants (BECo, 1993).

In 1993, the June mussel set that hampers *Chondrus* growth was not as dense as those that occurred in 1990 and 1992, so that the denuded zone was smaller in June than it had been in April, the opposite of the situation seen in 1990 and 1992 (BECo, 1994). The area of the denuded zone in September was slightly larger than it had been in September of 1990 and 1992, but the denuded zone in December was much larger than in previous years. In addition, the total affected area in December was the largest seen since 1983, rivaling the areas measured in the summers of 1990 and 1992; this may be partly due to the very early winter date (Dec. 2) of the survey and partly to damage imposed by a heavy infestation of the encrusting bryozoan, *Membranipora membranacea.*

In 1994, the denuded and total affected *Chondrus* areas in all four seasons were similar in size to those found during prior surveys (since 1989) at times of full or nearly full power plant operation (BECo, 1995). The dense mussel settlement seen in June obscured the boundary between the denuded and sparse/stunted regions and damage caused by the mussels to the *Chondrus* plants contributed to the enlargement of both *Chondrus* zones between the April and June surveys. The three-month fall power plant outage (September through November) appeared to have had no effect on the size of either the denuded or total affected *Chondrus* zones.

In 1995, the sizes of the denuded and total affected *Chondrus* areas were within the ranges seen in earlier surveys only for the early May and late June surveys (BECo, 1996). The impacted areas in October 1995 and February 1996 were much larger than those measured during any earlier fall and winter surveys and most closely approximated the impacted areas seen in September and December 1993. The two-month (April/May) spring power outage appeared to have no effect on the size of the *Chondrus* affected areas seen in May or June. However, the high plant operating capacity in effect from June 1995 through February 1996, in conjunction with a high mussel set in June, may have contributed to the largest fall and winter denuded and totally affected *Chondrus* zones seen since the current monitoring program began in 1983.

In 1996, the sizes of the denuded and totally affected *Chondrus* areas continued to increase over historical baseline measurements (1983 through February 1996) for the first three surveys. In December, the denuded zone declined in size to less than the winter historical baseline but was still the second largest ever observed in winter (BECo, 1997). The large *Chondrus* denuded and totally affected zones seen in each survey since October 1995 may be due to a combination of the high plant capacity that was in effect for the 18 months starting in July 1995 (mean = 92.6%), high summer water temperatures, and extremely dense settlement by mussel larvae in late spring that totally covered, possibly damaging, the algal plants.

In 1997, the sizes of the denuded and totally affected *Chondrus* zones were again larger than historical baseline measurements. In March 1997, the impacted areas were the second largest ever measured in spring. For the remaining three seasons, the areas of the denuded and totally affected zones were the largest ever seen for the corresponding season. The sizes of the denuded and totally affected zones in 1997 were extraordinarily large, larger than in 1996 for three surveys, and appeared not to track the reduction in the annual plant capacity factor from 90.5% in 1996 to 73.4% in 1997 that resulted from a two-month spring power outage. Turbidity from the dredging operation that took place from mid-June until the end of August, in conjunction with dense settlement by juvenile mussels that occurred sometime between March 28 and June 22, high summer water temperatures, and a moderately high 1997 power plant capacity, probably caused many *Chondrus* plants to die back to their holdfasts, yielding very large affected *Chondrus* zones.

In 1998, some recovery apparently took place in the outfall area compared to the very large denuded and totally affected *Chondrus* zones seen in the summer, fall, and winter of 1997. The areal measurements taken in March were somewhat higher than the historical maxima, but those made in June were well within those seen in previous surveys when the plant was in full or nearly full operation. The sizes of the *Chondrus* denuded and affected zones did increase dramatically between the June and October surveys, probably as a consequence of warm summer water temperatures combined with the extremely high plant capacity (97.1%) in effect in 1998, the highest seen in the history of plant operations.

4.0 CONCLUSIONS

- The denuded and totally affected *Chondrus* areas of the acutely impacted region off PNPS for the March survey were smaller than seen in the 1996 and 1997 spring surveys, although still larger than the historical baseline values (for each season, the largest area measured between 1983 and the 1995 survey seasons).

- The *Chondrus* denuded and affected zones measured during the June 1998 surveys were within the range seen in prior surveys when the plant was in full or nearly full operation. Some parameters were less than historical baseline values.

- Mussels settled earlier than usual so that juvenile mussels were common over the entire length of the CTL by March 2, 1998. The timing of this 'set' may have been accelerated by our anomalously warm winter.

- The areas of the denuded and total affected zones were greater in June than in March 1998, the usual trend observed when early summer *Chondrus* growth is adversely affected by high mussel settlement.

- The denuded and totally affected *Chondrus* areas increased dramatically between the June and October surveys, probably as a consequence of warm summer water temperatures combined with the highest plant capacity (97.1%) seen in the history of plant operations.

- In spite of the increase in size of the denuded and totally affected *Chondrus* zones between June and October, they were much smaller in October than they had been in the fall of 1997, indicating a recovery from the additional stress placed on the system from the dredging operations that occurred during the summer of 1997.

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APPENDIX A

Quality Control (QC) Protocol for Qualitative Transect Surveys at PNPS Outfall Area

1 Field Operation Planning

Field equipment is organized by the scientist in charge of dive operations; for 1999, the chief diver will be Mr. Erich Horgan of the Woods Hole Oceanographic Institution. Mr. Horgan has been a diver or chief diver on four quarterly surveys at the PNPS outfall site since April 1996. The survey equipment includes a boat and associated safety equipment; anchor and line; buoy and diver safety line; SCUBA gear, including a collecting bag; 100-ft kevlar line to be deployed across the mouth of the discharge canal; grapnel to aid in tying off the kevlar line to jetty boulders; the weighted 100-m central transect line (CTL), marked at 10-m intervals; two 30-m measuring tapes; compass; clipboard; data sheets on plasticized paper; two #1 pencils.

Every attempt will be made to perform the one dives between mid-September and mid-October as scheduled. Windows of opportunity, considering times of high tide (less current for the divers to contend with) and other commitments for both boats and personnel, will be blocked out in advance. Enough leeway will be planned to allow some flexibility for bad weather days.

2 Pre- and Post-dive Briefings

The chief diver and ENSR data manager, Isabelle Williams, will hold a pre- and post-dive briefing. The pre-dive briefing (may be made by telephone) will be the opportunity for determining the dive schedule, for reviewing data collection, and for informing the dive team whether or not any additional observations are requested. At this time, emphasis will be placed on the importance of the divers exploring the limits, and defining them, of the entire affected area so that a comprehensive survey map can be produced. The post-dive briefing (in person) will give the chief diver the opportunity to tell the data manager his immediate impressions about the region surveyed and whether any problems were encountered that need to be corrected.

3 Data Collection

A diver swimming perpendicularly away from the CTL, along the measuring line, records the distance away from the CTL line that changes in algal cover occur, from denuded to sparse and/or stunted *Chondrus* areas, and from sparse and/or stunted *Chondrus* to normal-looking *Chondrus*. Positions of other algal species, especially *Gracilaria*, a warm-water indicator, and kelp (*Laminaria*), a cold water indicator, are noted. Positions of animals, including mussels, starfish, crabs, and fish, and any unusual activities are also indicated.

For 1999, detailed observations will be made of *Chondrus,* including notes on robustness, color, occurrence of epiphytes, and qualitative descriptions of density and height. The divers will look for the presence of *Phyllophora*, the second dominant algal species in this community, throughout the survey area; if necessary, they will collect an algal sample from the normal *Chondrus* zone for examination in the laboratory. Particular attention will be paid to the boundaries of the high-density mussel array that may persist from the spring or summer settlement.

A sample blank data sheet is shown. A separate sheet is used for the north and south sides of the CTL. As the diver swims away from the CTL, distances and notes are recorded on the data sheet from left to right. For ease in working in an underwater environment algal cover is coded as indicated on the data sheet: 1 - denuded; 2 - stunted; 3 - sparse; 4 - normal. Codes for mussel cover are M1 - very dense; M2 - separated clumps; M3 - absent.

4 Data validation

The diver recording data during the field survey is responsible for reviewing his work at the end of the survey to ensure that the data are complete and accurate. The chief diver will submit to the data manager the original field notes and a survey report, previously reviewed for accuracy and completeness by other members of the dive team, that includes the data on the total extent of the denuded and stunted *Chondrus* zones as well as a general description of the area surveyed, including notes on flora and fauna observed. The data manager is responsible for reconciling data in the submitted field report to those recorded on the original data sheets. The data manager will discuss any questions that may arise with the chief diver. The data manager is responsible for constructing maps based on the survey data and for calculating the total areal extent of the denuded and totally affected *Chondrus* regions. All calculations performed by hand are checked for accuracy. The data manager is responsible for proof-reading the final computer-generated maps against the original maps for accuracy. All reports generated by the data manager will be reviewed by the ENSR Project Manager, Dr. James Blake.

5 Observation

The data manager will plan to accompany the divers on the 1999 field trips. She will be be on hand to accept any samples collected during those dives and to hear immediately the impressions of all divers about the conditions of the outfall area, as well as ensure that the entire affected area has been surveyed.

6 Meetings

The project and/or data manager will attend full Administrative-Technical Committee and Benthic Subcommittee meetings when appropriate. This will help ensure communication between ENSR, the field team, and the A-T Committee so that the quality of the benthic survey will be maintained as guided by the Committee.

Date:
Wind:
Visibility:

Divers Down @:
Divers Up @:

CTL (m)	NORTH/SOUTH	
30		CHONDRUS 1 DENUDED 2 STUNTED
40		3 SPARSE 4 NORMAL
50		MUSSELS M1 V. DENSE M2 CLUMPS
60		M3 ABSENT
70		
80		
90		
100		NORMAL CHONDRUS ROBUSTNESS________ COLOR____________
>100		EPIPHYTES________ HEIGHT__________ COLOR___________

Qualitative Transect Survey Field Data Sheet.`

ICHTHYOPLANKTON ENTRAINMENT MONITORING
AT PILGRIM NUCLEAR POWER STATION
JANUARY - DECEMBER 1998

Submitted to

Boston Edison Company

Boston, Massachusetts

by

Marine Research, Inc.

Falmouth, Massachusetts

April 1, 1999

APPENDIX B*. Geometric mean monthly densities and 95% confidence limits per 100 m^3 of water for the dominant species of fish eggs and larvae entrained at PNPS, January-December 1981-1998.

Note the following:

When extra sampling series were required under the contingency sampling regime, results were included in calculating monthly mean densities.

Shaded columns for certain months in 1984 and 1987 delineate periods when sampling was conducted with only salt service water pumps in operation. Densities recorded at those times were probably biased low due to low through-plant water flow (MRI 1994).

*Available upon request.

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SECTION I
EXECUTIVE SUMMARY

Sampling of entrained ichthyoplankton at PNPS followed the revised protocol initiated in April 1994. In January, February, and October through December three samples were taken every other week each month, weather permitting. From March through September single samples were taken three times every week in conjunction with the impingement monitoring study.

A total of 40 species were represented in the 1998 collections, two above the 23-year mean of 38 species. Numerical dominants during winter-early spring included yellowtail flounder, American plaice, fourbeard rockling, and Atlantic cod eggs along with sculpin, sand lance, and rock gunnel larvae. During the late spring-early summer season numerical dominants included tautog/cunner and mackerel eggs, along with larvae of the cunner, winter flounder, mackerel, rockling, hake, radiated shanny, and menhaden. During late summer-autumn, collections consisted primarily of tautog/cunner, windowpane, and rockling/hake, among the eggs as well as hake, rockling, cunner, Atlantic herring, windowpane, tautog, and menhaden larvae.

Comparisons of ichthyoplankton densities over the 1975-1998 time series suggested that Atlantic mackerel eggs, windowpane eggs, Atlantic menhaden larvae, and Atlantic herring larvae were entrained in relatively high numbers in 1998 consistent with overall trends in fish stocks. Larval winter flounder were also entrained in high numbers in 1998 for the second straight year although stock size estimates have varied without trend over the past nine years. Similar results were obtained for tautog and cunner larvae and, while stock size information is lacking for cunner, estimates for tautog indicate low stock abundance. Larval hake were also numerous in PNPS samples in 1997 and 1998, both nearly double the previous high. Like tautog, stock size estimates suggest that abundance is relatively low.

Unusually high entrainment densities, as defined under PNPS's notification plan, were identified on a number occasions in 1998. These involved tautog/cunner eggs, Atlantic menhaden eggs and larvae as well as the larvae of Atlantic mackerel, winter flounder, fourbeard rockling, hake, silver hake, tautog, cunner, and radiated shanny. The hakes displayed the most protracted period of high densities with unusually high numbers being recorded on 21 occasions in June, July, and

September. Among larval tautog densities all but one in July exceeded the notification level for that month with four of those exceeding all previous July observations..

Estimated numbers of eggs entrained by PNPS during 1998 ranged from 918,000 for searobins to 4,342,000,000 for tautog/cunner and totaled 5,124,000,000 for all eggs combined. Corresponding values for larvae ranged from 831,000 for seasnail to 370,218,000 for cunner, totaling 882,183,000 for all larvae combined.

Entrainment of winter flounder, cunner, and Atlantic mackerel, was examined in more detail dating back to 1980 using the equivalent adult (EA) approach. Winter flounder estimates for 1998 were 5,473 and 77,428 age 3 adults based on two suites of survival values, the highest yet observed because larvae were very abundant at PNPS during May and June of the 1998 season. These values were compared with estimates of commercial and recreational landings as well as local population estimates determined by trawl and mark-recapture. Recent, dramatic declines in commercial flounder landings reduce the value of that variable as a measure of EA impacts. The 1998 EA estimate from the larger staged approach amounted to 29% of the local area-swept population estimate and 75% of a mark-recapture estimate. A respective EA estimate for numbers of cunner eggs and larvae entrained in 1998 amounted to 1,522,731 fish. Comparable values for 1980-1997 ranged from 113,048 to 2,353,607 adult fish. The mean cunner EA value for the time series (428,119) represented less than one percent of an estimate of the number of cunner spawning in the PNPS area. For Atlantic mackerel EA estimates of 2,633 age 1 fish or 1,082 age 3 fish were obtained for 1998. Average values of 4,214 and 1,732 age 1 and 3 fish, respectively, were obtained over the 1980-1997 time series. Each of these values represented less than one percent of the commercial mackerel landings for area 514 which encompasses Cape Cod Bay and Massachusetts Bay. They also represented 0.08% of an estimate of the number of mackerel spawning in the PNPS area.

No lobster larvae were collected in 1998 for the third straight year. The total dating back to 1974 remains at 13.

SECTION II

INTRODUCTION

This report summarizes results of ichthyoplankton entrainment sampling conducted at the Pilgrim Nuclear Power Station (PNPS) from January through December 1998 by Marine Research, Inc. (MRI) for Boston Edison Company (BECo), under Purchase Order No. LSP009085, in compliance with environmental monitoring and reporting requirements of the PNPS NPDES Permit (U.S. Environmental Protection Agency and Massachusetts Department of Environmental Protection).

In an effort to condense the volume of material presented in this report, details of interest to some readers may have been omitted. Any questions or requests for additional information may be directed to Marine Research, Inc., Falmouth, Massachusetts, through BECO.

Plate 1 shows the ichthyoplankton sampling net being deployed on station in the PNPS discharge canal approximately 30 meters from the headwall.

SECTION III

METHODS AND MATERIALS

Monitoring

Entrainment sampling at PNPS, begun in 1974, had historically been completed twice per month during January and February, October-December; weekly during March through September; in triplicate at low tide. Following a PNPS fisheries monitoring review workshop in early 1994, the sampling regime was modified beginning April 1994. In January, February, and October through December during two alternate weeks each month single samples were taken on three separate occasions. Beginning with March and continuing through September single samples were taken three times every week. During autumn and winter months when sampling frequency was reduced, sampling was postponed during onshore storms due to heavy detrital loads. The delayed sample was taken during the subsequent week; six samples were ultimately taken each month.

To minimize costs, sampling was linked to the impingement monitoring program so that collections were made Monday morning, Wednesday afternoon, and Friday night regardless of tide (see Impingement Section). All sampling was completed with a 60-cm diameter plankton net streamed from rigging mounted approximately 30 meters from the headwall of the discharge canal (Figure 1). Standard mesh was 0.333-mm except from late March through late May when 0.202-mm mesh was employed to improve retention of early-stage larval winter flounder *(Pleuronectes americanus)*. Sampling time in each case varied from 8 to 30 minutes depending on tide, higher tide requiring a longer interval due to lower discharge stream velocities. In most cases, a minimum quantity of 100 m^3 of water was sampled although at astronomical high tides it proved difficult to collect this amount even with long sampling intervals since the net would not inflate in the low current velocity near high tide. Exact filtration volumes were calculated using a General Oceanics Model 2030R digital flowmeter mounted in the mouth of the net. Near times of high water a 2030 R2 rotor was employed to improve sensitivity at low velocities.

For the most part sampling followed the sample design, however sampling was not completed on January 21, February 25, May 11, August 28, October 12, and October 14 due to stormy seas. Sampling under such conditions results in such heavy detrital loads that processing the samples is all but impossible. (In the past when storm samples have been processed, ichthyoplankton has been

Plate 1. Plankton net streaming in the discharge canal at Pilgrim Station for the collection of fish eggs and larvae (lobster larvae are also recorded). A single, six-minute collection can contain several thousand eggs and larvae representing 20 or more species.

uncommon.). Sampling was also not possible on April 17, July 24, or August 7 because condenser backwashes were underway.

All samples were preserved in 10% Formalin-seawater solutions and returned to the laboratory for microscopic examination. A detailed description of the analytical procedures appears in MRI (1988). As in past years, larval winter flounder were enumerated in four developmental stages as follows:

Stage 1 - from hatching until the yolk sac is fully absorbed (2.3-2.8 mm TL).

Stage 2 - from the end of stage 1 until a loop or coil forms in the gut (2.6-4 mm TL).

Stage 3 - from the end of stage 2 until the left eye migrates past the midline of the head during transformation (3.5-8 mm TL).

Stage 4 - from the end of stage 3 onward (7.3-8.2 mm TL).

Similarly larval cunner *(Tautogolabrus adspersus)* were enumerated in three developmental stages:

Stage 1 - from hatching until the yolk sac is fully absorbed (1.6-2.6 mm TL).

Stage 2 - from the end of stage 1 until dorsal fin rays become visible (1.8-6.0 mm TL).

Stage 3 - from the end of stage 2 onward (6.5-14.0 mm TL).

Samples were examined in their entirety for larval American lobster (*Homarus americanus*). When collected these were staged following Herrick (1911).

Notification Provisions

When the Cape Cod Bay ichthyoplankton study was completed in 1976, provisions were added to the entrainment monitoring program to identify unusually high densities of fish eggs and larvae. Once identified and, if requested by regulatory personnel, additional sampling could be conducted to monitor the temporal and/or spatial extent of the unusual occurrence. An offshore array of stations was established which could be used to determine whether circumstances in the vicinity of Rocky Point, attributable to PNPS operation, were causing an abnormally large percentage of ichthyoplankton populations there to be entrained or, alternatively, whether high entrainment levels simply were a reflection of unusually high population levels in Cape Cod Bay. The impact attributable to any large entrainment event would clearly be greater if ichthyoplankton densities were particularly high only close to the PNPS shoreline. In past years when high densities were identified, additional entrainment sampling was requested by regulatory personnel and the unusual density in most cases was found to be of short duration (<2 days). With the change in 1994 to Monday, Wednesday, Friday sampling the temporal extent of any unusual density can be more clearly discerned without additional sampling effort.

Until 1994 "unusually abundant" was defined as any mean density, calculated over three replicates, which was found to be 50% greater than the highest mean density observed during the same month from 1975 through to the current year. Restricting comparisons to monthly periods damped the large seasonal variation so readily apparent with ichthyoplankton. Starting with 1994 "unusually abundant" was redefined. On a month-by-month basis for each of the numerically dominant species all previous mean densities over three replicates (1974-1993; to be updated each year) were examined and tested for normality following logarithmic transformation (Ryan and Joiner 1976). Single sample densities obtained from 1994-1997 were added to the pool within each month. Where data sets (for example, mackerel eggs taken in June) fit the lognormal distribution, then "unusually large" was defined by the overall log mean density plus 2 or 2.58 standard deviations.[1] Log densities were back-transformed to make them easier to interpret, thus providing geometric means. In cases where data sets did not fit the lognormal distribution (generally months when a species was frequently but not always absent, i.e., many zeros occurred), the mean and standard deviation was computed using the delta-distribution (see for example Pennington 1983). The same mean plus standard deviation guideline was applied.

The decision to rely on 2 standard deviations or 2.58 standard deviations was based on the relative importance of each species. The more critical criterion was applied to species of commercial, recreational, or biological interest, the less critical to the remaining species (i.e., relatively greater densities were necessary to trigger notification). Species of commercial, recreational, or biological interest include Atlantic menhaden *(Brevoortia tyrannus)*, Atlantic herring *(Clupea harengus)*, Atlantic cod *(Gadus morhua)*, tautog and cunner (the labrids; *Tautoga onitis/Tautogolabrus adspersus)*, sand lance *(Ammodytes* sp.), Atlantic mackerel *(Scomber scombrus)*, windowpane

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[1]Normal distribution curve theory states that 2.5% of the measurements in a normally distributed population exceed the mean plus 1.96 standard deviations (= s, we rounded to 2 for simplicity), 2.5% lie below the mean minus 1.96 standard deviations. Stated another way 95% of the population lies within that range and 97.5% lies below the mean plus 1.96s. Likewise 0.5% of measurements exceed the mean plus 2.58s, 99% lie within the range of the mean ± 2.58s, 99.5% lie above the mean + 2.58s.

(*Scophthalmus aquosus*), American plaice (*Hippoglossoides platessoides*), and winter flounder. Table 1 provides summary data for each species of egg and larva by month within these two categories showing the 1998 notification level.

A scan of Table 1 will indicate that, in cases where the long-term mean amounts to 1 or 2 eggs or larvae per 100 m^3, the critical level is also quite small. This situation occurred during months when a given species was obviously uncommon and many zeros were present in the data set with an inherent small standard deviation. The external reference distribution methodology of Box et al. (1975) was also employed. This procedure relies on a dotplot of all previous densities for a species within month to produce a reference distribution. Densities exceeding either 97.5 or 99.5% of the reference set values were considered unusually high with this procedure.

Table 1. PNPS ichthyoplankton entrainment notification levels for 1998 by species category and month. See text for details.

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.
January			
LARVAE			
Atlantic herring[2]	0.2	1	
Sculpin			
Rock gunnel	0.8		1.4
Sand lance[2]	5	11	
February			
LARVAE			
Atlantic herring[2]	0.1	0.8	
Sculpin	2		65
Rock gunnel	4		99
Sand lance[2]	16	29	
March			
EGGS			
American plaice[2]	2	3	
LARVAE			
Atlantic herring[2]	0.9	1.3	
Sculpin	17		608
Seasnails	0.6		1
Rock gunnel	10.7		723
Sand lance[2]	7	164	
Winter flounder[2]	0.4	0.7	
April			
EGGS			
American plaice[2]	3	32	
LARVAE			
Atlantic herring[2]	1	2	
Sculpin	15		391
Seasnails	6		10
Radiated shanny	3		6
Rock gunnel	4		142
Sand lance[2]	21	998	
Winter flounder[2]	7	12	

Table 1 (continued).

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.
May			
EGGS			
Labrids[2]	36	3514	
Atlantic mackerel[2]	18	4031	
Windowpane[2]	9	147	
American plaice[2]	2	15	
LARVAE			
Atlantic herring	0.7	1.1	
Fourbeard rockling	2		5
Sculpin	3		4
Radiated shanny	7		236
Atlantic mackerel[2]	1.8	3.5	
Sand lance[2]	37	59	
Atlantic mackerel	2	4	
Winter flounder[2]	9	123	
Seasnails	7		208
June			
EGGS			
Atlantic menhaden[2]	10	16	
Searobins	3		4
Labrids[2]	958	21599	
Atlantic mackerel[2]	63	3515	
Windowpane[2]	27	261	
American plaice[2]	1	2	
LARVAE			
Atlantic menhaden[2]	6	10	
Fourbeard rockling	9		634
Hake	0.3		1
Cunner[2]	6	265	
Radiated shanny	1		15
Atlantic mackerel[2]	91	155	
Winter flounder[2]	7	10	
July			
EGGS			
Atlantic menhaden[2]	2	4	
Labrids[2]	615	13349	
Mackerel[2]	9	16	
Windowpane[2]	12	156	

Table 1 (continued).

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.
<u>July</u>			
LARVAE			
Atlantic menhaden[2]	2	3	
Fourbeard rockling	6		9
Hake	0.7		1
Tautog[2]	2	2	
Cunner[2]	7	318	
Mackerel[2]	2	3	
<u>August</u>			
EGGS			
Searobins	4		6
Labrids[2]	23	936	
Windowpane[2]	15	136	
LARVE			
Atlantic menhaden[2]	0.4	1	
Fourbeard rockling	6		10
Hake	2		4
Tautog[2]	1.6	2.2	
Cunner[2]	10	15	
<u>September</u>			
EGGS			
Labrids[2]	2	3	
Windowpane[2]	11	159	
LARVAE			
Fourbeard rockling	4		6
Silver hake[2]	1	2	
Hake	5		9
Tautog[2]	1	2	
Cunner[2]	1	2	
<u>October</u>			
EGGS			
Atlantic menhaden[2]	2	6	
Windowpane[2]	1	2	
LARVAE			
Atlantic menhaden[2]	2.3	4	
Fourbeard rockling	1		16
Hake	1		2

Table 1 (continued).

Densities per 100 m³ of water:	Long-term Mean[1]	Mean + 2 std.dev.	Mean + 2.58 std.dev.
November			
LARVAE			
Atlantic menhaden[2]	0.4	1	
Atlantic herring[2]	4	8	
December			
LARVAE			
Atlantic herring[2]	2	3	

[1]Geometric or Delta Mean.

[2]Species of commercial, recreational, or biological interest for which more critical notification level will be used.

SECTION IV

RESULTS

A. Ichthyoplankton Entrained - 1998

Population densities per 100 m^3 of water for each species listed by date, station, and replicate are presented for January-December 1998 in Appendix A (available upon request). The occurrence of eggs and larvae of each species by month appears in Table 2. Ichthyoplankton collections are summarized below within the three primary spawning seasons observed in Cape Cod Bay waters: winter-early spring, late spring-early summer, and late summer-autumn.

Winter-early spring spawners (January-April)

Many species spawning during this season employ a reproductive strategy which relies on demersal, adhesive eggs not normally entrained. As a result, more species are typically represented by larvae than by eggs during winter-early spring. Considering the season as a whole, 9 species were represented by eggs, yellowtail flounder (*Pleuronectes ferrugineus*), American plaice, fourbeard rockling (*Enchelyopus cimbrius*), and Atlantic cod being numerically dominant (Figure 2). Yellowtail eggs first appeared in the collections early in April at which time they represented 46% of the month's total with a geometric mean density of 8 per 100 m^3 of water. American plaice eggs appeared at low densities in February and March, then increased in number in April when a geometric mean density of 4 per 100 m^3 accounted for 24% of the month's total. A single rockling egg was collected in February with the remainder of the seasonal total being taken in April. During that month they accounted for 19% of all eggs with a monthly geometric mean density of 3 per 100 m^3 of water. Atlantic cod eggs were present in the collections each month reaching a high geometric mean density of 2 per 100 m^3 in February. That density accounted for 77% of the month's egg catch.

Larval collections during the winter-early spring season contained 19 species of fish. Numerical dominants consisted of sculpin (*Myoxocephalus spp.)*, sand lance, and rock gunnel (*Pholis gunnellus*). Sculpin, a group actually consisting of three species, represented 16% of the January catch, 72% of the February catch, 48% of the March catch, declining to 19% in April. Respective monthly geometric mean densities for the group as a whole amounted to 0.2, 13, 18, and 9 per 100 m^3 of water. Among the three species of larval sculpin the grubby (*M. aenaeus*) was most abundant over the season as a whole accounting for 96.5% of the group total. The shorthorn sculpin (*M.*

scorpius) followed at 2.5% and the longhorn sculpin (*M. octodecemspinosus*) at 1%. Larval sand lance were collected throughout the January-April period accounting for 33% of the seasonal total and reaching a peak monthly geometric mean density of 19 per 100 m^3 of water in April. Rock gunnel were also collected throughout the period adding 14% to the seasonal larval total. They reached a peak geometric mean density of 7 per 100 m^3 of water in both February and March.

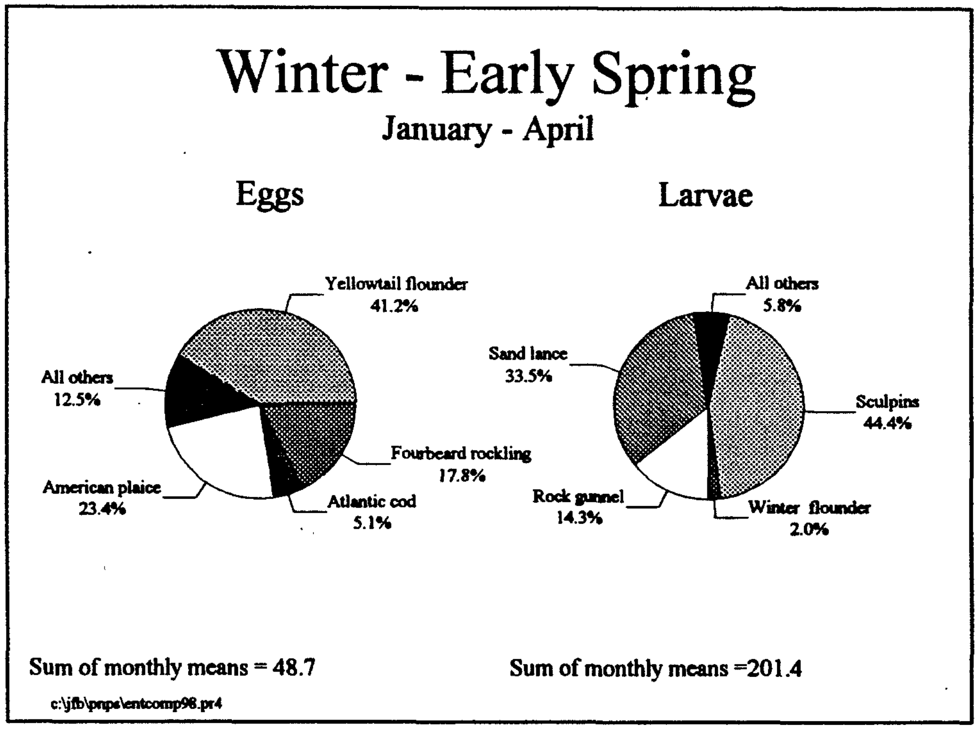


Figure 2. Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the winter-early spring season, 1998. Percent of total and summed monthly means for all species are also shown.

Late Spring-Early Summer (May - July)

Egg and larval densities, particularly among species with pelagic eggs, typically increase during this season along with expanding day length and rising water temperature. Considering both eggs and larvae together, 18 species were represented in May, increasing to 21 species in June and 24 species in July. Numerical dominants included tautog/cunner, and mackerel among eggs and cunner, winter flounder, mackerel, fourbeard rockling, hake (*Urophycis spp.*), radiated shanny (*Ulvaria subbifurcata*), and Atlantic menhaden among the larvae (Figure 3).

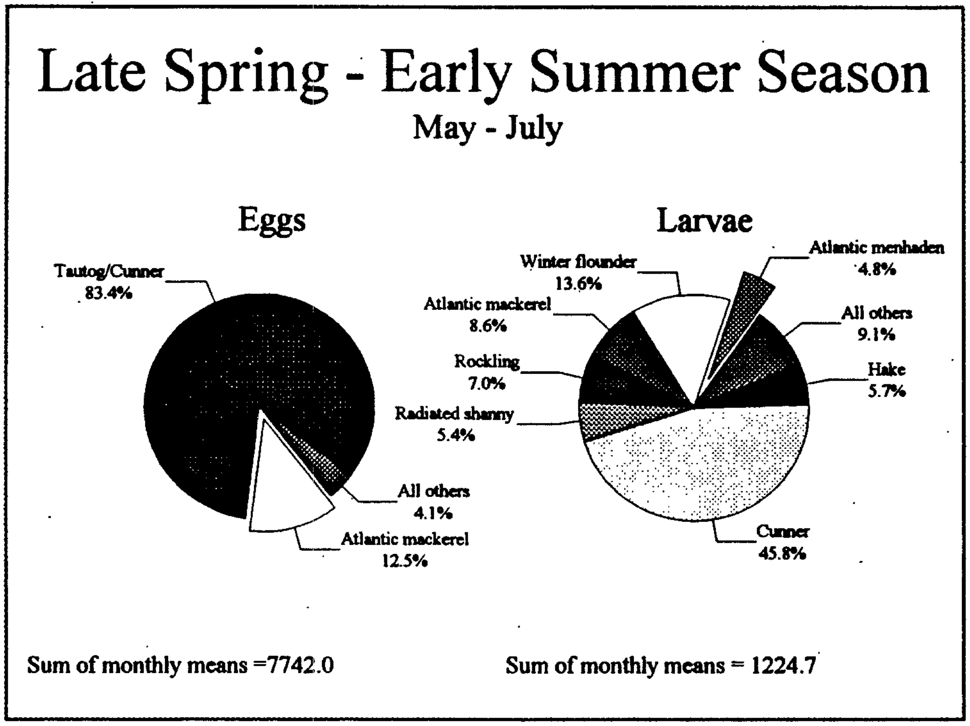


Figure 3. Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the late spring - early summer season 1998. Percent of total and summed monthly means for all species are also shown.

Tautog/cunner eggs accounted for 26% of the May total, 95% of the June total, and 94% of the July total. Respective monthly geometric means were 52, 1297, and 269 per 100 m^3. Based on a study completed at PNPS in 1975 and 1976 (MRI 1978a), over 90% of tautog/cunner eggs taken in the PNPS area are believed to have been spawned by cunner. Mackerel eggs contributed an additional 59% to the May total and 1% to the June total with monthly geometric means of 196 and 11 per 100 m^3. Mackerel eggs were not present in the July collections.

Cunner larvae first appeared during the week of May 25 accounting for less than 1% of the month's total catch. They increased in number in June with a geometric mean density of 14 per 100 m^3 accounting for 50% of the larvae collected. In July they reached a mean density of 136 per 100 m^3 while accounting for 59% of the catch. Larval winter flounder were the overall numerical dominant in May when they contributed 45% to the month's total with a monthly geometric mean of 28 per 100 m^3. In June they accounted for 18% of the total with a mean of 12 per 100 m^3. Larval flounder were present into the first week of July but overall they contributed little to that month's catch. Larval mackerel first appeared in mid May and continued to appear in collections until mid July. They contributed 21%, 15%, and 0.3% to the three respective monthly totals with geometric monthly means of 3, 8, and 1 per 100 m^3 of water. Fourbeard rockling which occur nearly year round in egg and/or larval form contributed an additional 4, 6, and 9% to the May, June, and July catch with monthly geometric means of 5, 10, and 32 per 100 m^3. Hake larvae were collected from late May through the month of July. Monthly geometric means of 0.2, 2, and 17 per 100 m^3 represented 0.2, 2, and 10% of the three respective month's catch. Radiated shanny declined in number through the season. They accounted for 24% of the May total with a geometric mean of 13 per 100 m^3, 4% of the June total with a geometric mean of 4 per 100 m^3, and 0.2% of the July total with a geometric mean of 0.5 per 100 m^3 Lastly, larval menhaden first appeared in late May and increased in number through June into July. Overall they contributed less then 1% of the May catch, 1% of the June catch, and 8% of the July catch. Monthly geometric means amounted to 0.03, 2, and 28 per 100 m^3 respectively.

Late Summer - Autumn Spawners (August - December)

This season is typically described as one where a marked decline in both overall ichthyoplankton density and number of species occurs. Considering egg and larval stages combined, 20 species were taken in August, 19 were taken in September, followed by 9 in both October and November dropping to 6 in December. Numerical dominants included tautog/cunner, windowpane, and rockling/hake among the eggs, hake, rockling, cunner, Atlantic herring, windowpane, tautog, and, menhaden among the larvae (Figure 4). Tautog/cunner eggs, presumably primarily cunner, accounted for 64% of all eggs taken in August with a geometric mean of 28 per 100 m^3. Their numbers declined into September when they accounted for 6% of the month's total with a geometric mean of 1 per 100 m^3. Small numbers of these eggs were occasionally taken through the remainder of the seasonal period. Windowpane eggs are reported under the *Paralichthys-Scophthalmus* group because they cannot be distinguished from fourspot flounder eggs. Because windowpane larvae are far more abundant then fourspot larvae in PNPS collections, the majority of the grouped eggs are assumed to be in fact windowpane. These eggs occurred from August through the first half of October accounting for 20%, 63%, and 8% of those three monthly totals; geometric monthly means were 37, 17, and 0.4 per 100 m^3 respectively. Rockling and hake eggs were entrained from August through

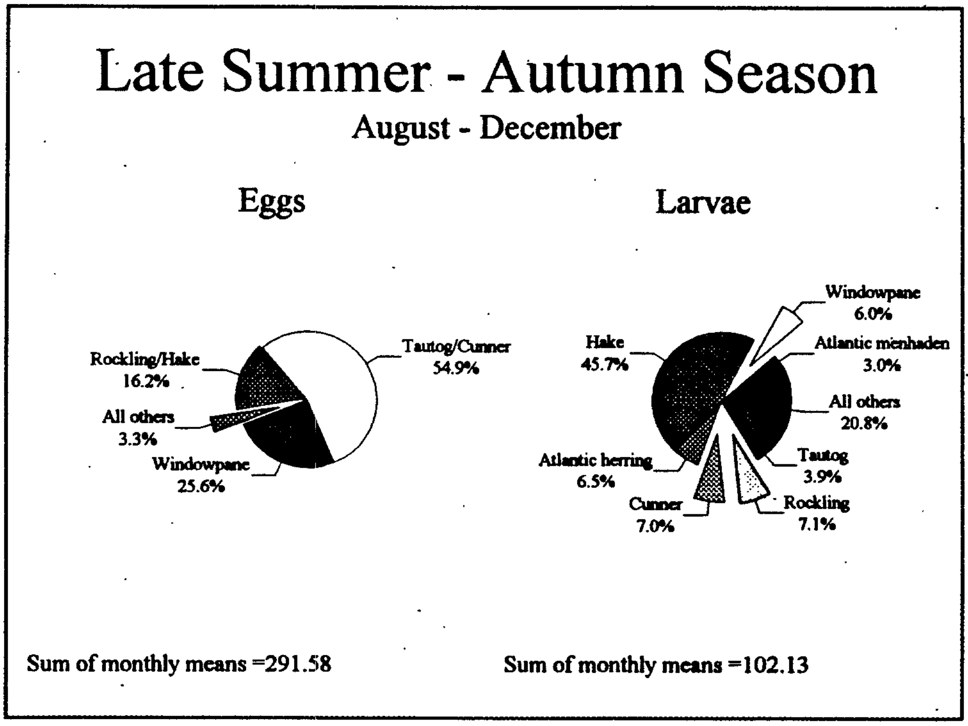


Figure 4. Dominant species of fish eggs and larvae found in PNPS ichthyoplankton samples during the late summer - autumn season 1998. Percent of total and summed monthly means for all species are also shown.

October with monthly combined geometric means ranging from 2 to16 per 100 m^3 and percent contribution ranging from 14 to 40%. Based on collection of specifically identifiable late-stage eggs, hake appeared to be somewhat more abundant than rockling.

Among the larvae, hake were collected in August at a mean density of 4 per 100 m^3, increasing in September to a mean density of 7 per 100 m^3. While absent from the October collections a small number appeared in November at a mean density of 0.6 per 100 m^3. These densities accounted for from 10 to 69% of those three monthly larval totals. Larval rockling paralleled hake in being collected during August, September, and November. They accounted for 13, 5, and 3% of those three monthly totals with respective geometric mean densities of 2, 2, and 0.2 per 100 m^3. Cunner, ranking third among the seasonal dominants, were present in samples from August and September at monthly geometric mean densities of 3 and 0.5 per 100 m^3; these densities accounted for 19 and 1 % of those monthly totals. Larval Atlantic herring, originating from the fall spawning season, appeared only in November and December. Respective geometric mean densities of 1 and 2 per 100 m^3 accounted for 48 and 64% of those monthly collections. Windowpane, like hake and rockling appeared regularly in August and September, skipped October, and reappeared in November. With respective geometric means of 1, 2, and 1 per 100 m^3 they represented between 5 and 14% of those monthly totals. Larval tautog were regularly present in August and September only, accounting for 4 and 5% of those monthly totals with geometric means of 1 and 2 per 100 m^3. Lastly, menhaden larvae were taken each month of the seasonal period except for December. They accounted for 4% or the August catch with a geometric mean of 0.7, 1% of the September catch with a geometric mean of 0.4, 20% of the October catch with a geometric mean of 0.5, and 8% of the November catch with a geometric mean of 0.5 per 100 m^3

B. Notification Plan

Ichthyoplankton densities reaching the unusually high level during the 1998 sampling season occurred on a number of occasions. These involved Atlantic menhaden and cunner eggs and larvae as well as the larvae of fourbeard rockling, hake, silver hake, tautog, mackerel, radiated shanny, and winter flounder (Table 3). Since winter flounder densities recorded during the first three weeks of May were based on 0.202-mm mesh samples they were scaled downward using mesh conversion factors for stage 1 and 2 larvae to make them comparable to past 0.333-mm mesh based densities. Among the above species, the hakes displayed the most protracted period of high numbers with unusually high densities of larvae being recorded on 21 occasions during June, July, and September. On two of the occasions in June and four of the occasions in July hake densities exceeded all previous densities for those respective months dating back to 1975. In particular a density of 248 larvae per 100 m^3 was recorded on July 27 exceeding the previous July high of 50 per 100 m^3 by a factor of five. Among tautog densities all but one in July exceeded the notification level for that month. Four of those (38 to 269 per 100 m^3) exceeded all previous July observations, 29 per 100 m^3 being the previous high. Menhaden larvae did not exceed all previously recorded densities on any occasion in July 1998 although eleven of the thirteen observations were high enough to exceed the notification level.

Additional notification level densities are mentioned in the next section.

C. Multi-year Ichthyoplankton Comparisons

A master species list for ichthyoplankton collected from the discharge canal at PNPS appears in Table 4; the years during which each species was represented is indicated for 1975 through 1998. A total of 40 species were represented in the 1998 collections, two above the 23-year mean of 38 species.

Appendix B (available upon request) lists geometric mean monthly densities along with 95% confidence limits for each of the numerical dominants collected during each year dating back to 1981. Geometric means are reported because they more accurately reflect the true population mean when the distribution of sample values are skewed to the right as is commonly the case with plankton data. Generally low values obtained for both eggs and larvae during April-June 1984 and 1987 were shaded because low through-plant water volumes during those months probably affected densities of ichthyoplankton (MRI 1994); shaded values were omitted from the discussion below. Entrainment data collected from 1975-1980 remain in an outdated computer format requiring conversion before geometric mean densities can be generated. These years were therefore excluded from Appendix B but are discussed in the multi-year comparisons if noteworthy.

To help compare values over the 18-year period, egg data were plotted in Figure 5 for those species whose combined total represented 90% or more of the 1998 egg catch. For this figure cod and pollock eggs were combined with the *Enchelyopus-Urophycis-Peprilus* group, and labrids and yellowtail flounder were combined with the labrid-*Pleuronectes* group. For each category shown, the highest monthly geometric means obtained from 1981 through 1997 were joined by solid lines as were the lowest monthly geometric means, and the area between was shaded, indicating the range of these values. Monthly geometric mean values for 1998were joined by a solid line. Alongside each plot is a bar graph showing annual abundance indices for each year. These were generated by integrating the area under each annual curve using trapezoidal integration[2]. One set of bars was based on geometric monthly means and the other, longer time series, on arithmetic monthly means (1975-1998). Appendix B and Figure 6 contain corresponding data for the 13 numerically dominant species of fish larvae, those accounting for 99% of the 1998 catch, as well as total larvae (all species combined). As mentioned for eggs, low values obtained for both eggs and larvae during April

[2] Curve integration results in units of (Numbers x days) per 100 m^3 of water.

through August 1984 and 1987 were flagged in these figures and omitted from the following discussion.

In many cases densities of fish eggs and larvae vary considerably from year to year. For example, over the 17-year geometric mean time series the highest annual abundance index divided by the lowest for Atlantic menhaden eggs amounted to 292. In spite of such pronounced variation, no consistent upward or downward trend was apparent over the time series for many species such as menhaden and windowpane eggs, sculpin and rock gunnel larvae. Following are noteworthy observations concerning the multi-year time series. Since densities of each ichthyoplankton species rise from and fall to zero over the course of each respective occurrence season, inter-year comparisons are often conveniently made within monthly periods.

- Atlantic menhaden eggs were relatively abundant at PNPS on three occasions in June and five occasions in July1998 based on the notification program criteria (see above). In spite of these observations the annual index of abundance for menhaden eggs was not remarkable. The geometric mean index ranked 7th over the 1981-1998 period and the arithmetic index ranked 11th over the 1975-1997 period. While egg abundance was not remarkably high in 1998, larval menhaden abundance was considered so for the second straight year. The annual geometric mean abundance index (984) ranked second behind 1997 (1145) dating back to 1981 and the arithmetic index (1893) ranked third behind 1997 (2801) and 1981 (2708).

  Menhaden are coastal migrants which travel in schools that can often be quite dense. For example, the great variability in numbers of eggs taken at PNPS probably reflects not only numbers of adults in the surrounding waters but variability in the distance from PNPS at which spawning takes place. Spawning stock biomass increased from 1993 through 1995 (Cadrin and Vaughan 1997) which is consistent with the observed increase in egg and larval densities in 1997 and larval densities alone in 1997 and 1998.
- Atlantic cod eggs were typically collected in low numbers at PNPS during winter months from 1975-1987 (5 per 100 m^3 of water for example). Following 1987 they became uncommon particularly during January and February. None were taken either month in 1993 or 1994 and only one was taken in 1995. In 1996 collections rose to three eggs, all taken

in February. The gadidae-*Glyptocephalus* group in general showed a significant decline from 1975 to 1993 ($p<0.001$), based on a nonparametric sign test, which is consistent with the downward trend reported for Atlantic cod and witch flounder stocks apparently resulting, at least in part, to overexploitation (NOAA 1995, NFSC 1998). Annual geometric mean indices suggest the decline has ended if not reversed, at least locally, since values for 1994 through 1997 appear stable at about three times the low value recorded in 1993 (39) and the 1998 geometric index (149) was the highest since 1989 (158).

- Eggs of the fourbeard rockling and closely related hake (grouped in the early developmental stages with far less common butterfish as *Enchelyopus-Urophycis-Peprilus* ; MRI 1988) have been uncommon in recent years. Trend analysis using the longer-term arithmetic time series indicated that a significant downward trend occurred from 1978 through 1996 ($p = 0.05$) in spite of a moderate catch in 1995. Any suggestion of a reversal in 1995 was erased by the 1996 value which was similar to values observed from 1992 to 1994. In spite of relatively high densities in April 1997, the 1997 indices (3819 and 1621) represented but a slight improvement over 1996 (2889 and 1299). The 1998 indices (5078 and 2687) suggest an upward trend is underway. Fourbeard rockling dominate within this grouping based on late-stage egg as well as larval collections. Since this a small bottom fish with little or no commercial value, stock size data are not available with which to compare trends. Hake on the other hand contribute to the commercial bottom fishery, and stocks in the Gulf of Maine and northern Georges Bank are considered to be underexploited. Stock abundance of red hake on southern Georges Bank and in Massachusetts waters are relatively low according to the Northeast Fisheries Center survey index (NOAA 1995).
- Searobin eggs (*Prionotus spp.*) were relatively abundant at PNPS from 1983 through 1987. Relative to that period of time numbers have been low with 1998 particularly so. The geometric curve index for 1998 (26) ranked second to last ahead of only 1990 (24) and the longer arithmetic time series (53) ranked last dating back to 1975. Massachusetts Division of Marine Fisheries resource survey trawls showed relatively high abundance during the late 1970's through the mid-1980's followed by a sharp decline through the early 1990's (McBride et al. 1998). These data appear to be reflected in the PNPS larval data.

- Tautog/cunner eggs, composed primarily of cunner (Scherer 1984) appeared to be in a downward trend from the late 1970's through 1994 although a sign test failed to confirm it using the conventional 95% significance level ($p = 0.055$). In contrast the arithmetic and geometric indices both showed an increase in density in 1995, the geometric index continuing to rise in 1996. The 1995 arithmetic index appeared exceptionally high and disproportionate to the geometric value due to a single high density in June (37,282 per 100 m^3 of water) which greatly skewed the arithmetic mean for that month. The 1997 indices declined from 1996 but remained well above the low values observed in 1990, 1991, and 1994. Indices rose again in 1998, the geometric value nearly equally the 1996 index. The arithmetic index was disproportionately high due to two high densities in June. The downward trend noted through 1994 is consistent with finfish observations in the PNPS area as well as impingement collections at the Station (Lawton et al. 1995). Changes in sampling protocols at PNPS have negated the ability to monitor general cunner population trends beyond 1994 which in the past were sampled by gill net, trawl, and diver surveys. Numbers impinged appeared to systematically decline from 1980 through 1992 (annual totals dropped from 116 to as low as 2 in 1988), then increase from 1993 (104) through 1995 (288). They remained high in 1996 (211) which appeared to roughly parallel the egg abundance data. The impingement total for 1997 (39) and 1998 (76; see Impingement Section) represented a substantial drop relative to the preceding four years and appeared out of step with the ichthyoplankton collections.

  Eggs of the yellowtail flounder were also relatively abundant in April 1997and again in 1998. While early staged eggs of this species are similar to and grouped with the labrids, they are believed to account for all eggs of that type collected in April since the labrids are not likely to spawn until May. The geometric mean density for that month in 1997 was 4.6 per 100 m^3, increasing to 7.7 in 1998, both exceeding the previous high of 1.8 per 100 m^3 noted in 1983 (Figure 5). Stock assessment information shows a slight increase since 1994, perhaps explaining the increase in egg abundance (NFSC 1998).
- While mackerel egg densities declined in 1997, they increased in number in 1998, continuing to show that they have clearly been more abundant since 1988 when compared to the 1975

through 1987 period. A sign test using the arithmetic index time series supported this upward trend ($p<0.006$). Mackerel eggs typically display a sharp peak in their abundance curve often with one or two very high densities. For example in May 1995 a single density of 19,203 eggs per 100 m^3 was recorded on May 26, dropping to 557 eggs per 100 m^3 on the 29th. The second highest density occurred on June 9 at 4,754 per 100 m^3. Due to these brief sharp peaks, arithmetic and geometric indices are often quite far apart (Figure 5). Entrainment of high densities of mackerel eggs over the past decade is consistent with a dramatic rise in stock biomass attributable to reductions in foreign fishing and under exploitation by U.S. fishermen (Overholtz 1993, NOAA 1995, NFSC 1996).

- Windowpane eggs, assuming, based on larval collections, that they predominate within this egg group, have increased from 1994 through 1998. The annual geometric index for 1997 (3144) was essentially equal to 1996 (3147) but the upward trend continued in 1998 (4553). Over the entire 24-year time series the arithmetic index for 1998 (6634) ranked fourth. In general these eggs have not shown wide variations in number, at least not compared with other species regularly entrained. Consistent with the recent egg collections, current abundance indices for windowpane, based on Massachusetts Division Of Marine Fisheries spring and fall surveys, suggest that stocks increased steadily from 1991 through 1996 (Steve Correia, MDMF, personal communication).
- For American plaice eggs, the arithmetic time series shows a more or less steady decline from 1978 to 1986 followed by a steady increase through 1995. While 1996 represented a drop in overall abundance, 1997 and 1998 turned upward again. Patterns of egg abundance appear to follow, in a general way estimates of finfish abundance According to the Northeast Fisheries Center survey results for Massachusetts (NFSC 1996), plaice were at relatively low abundance levels in the mid 1980's, when egg entrainment was also at its lowest, then rebounded following the production of a strong year class in 1987. They again declined from 1989 through 1993 and, while the finfish series does not yet run to 1997 or 1998, they appear to have begun to increase again.
- Atlantic herring larval abundance indices have proven valuable in management of herring stocks on Georges Bank, Nantucket Shoals, and in the Northeast Atlantic in general (see for

example, Smith and Morse 1993). The stock was seriously depleted during the 1970's and collapsed on Georges Bank in 1976 (Anthony and Waring 1980, Smith and Morse 1993). The stock has increased more or less steadily since 1986 following reductions in fishing pressure. Presently the Atlantic coast stock is increasing in size, projected to continue doing so through into the year 2000, and considered to be extremely underutilized (NFSC 1998). Larval collections at PNPS from 1994 through 1997 reflect the general increase in stock size, the geometric index for those four years ranking among the top five. Although numbers dropped in 1998 the geometric index (143) remained among the top ten over the 1981-1998 time series (Figure 6).

- Fourbeard rockling larvae were abundant in 1998 particularly in July when the monthly geometric mean of 32 per 100 m^3 exceeded the previous July high dating back to 1981 of 6 per 100 m^3. Overall the annual geometric mean index of 1620 exceeded the previous high of 1086 recorded in 1989. The arithmetic index (2945) ranked second behind 1977 (5001). As mentioned above under eggs, the rockling is a small bottom fish with little or no commercial value and stock size data are not available with which to compare trends.
- Larval hake were abundant in 1997 and again in 1998. Respective geometric mean indices amounted to 994 and 932, both exceeding the previous high of 514 recorded in 1985. Arithmetic means for the two most recent years ranked second and third dating back to 1975. Relatively high larval densities in 1998 were clearly reflected in the notification program mentioned above. Data available through 1995 suggest that hake stocks in Southern New England have declined by about 50% since the late 1960's and surveys in Massachusetts waters confirm that abundance is relatively low (NFSC 1996). High larval abundance at PNPS in 1997 and 1998 may indicate production of a strong year class or simply reflect a localized spawning aggregation.
- Larval seasnail (*Liparis atlanticus*) were uncommon at PNPS in 1998, the geometric index (32) amounting to less than half the previous low recorded in 1992 over the 18-year geometric time series and the arithmetic index also ranked last over the 24-year series. Since these fishes typically reach a length of less than 6 inches and they have no commercial or

recreational significance no stock size data are available with which to compare the larval abundance.

- In spite of unremarkable egg abundance in 1998, larval cunner and in particular larval tautog were relatively abundant in PNPS entrainment samples. Both species were particularly abundant in July exceeding the previous high mean density for that month (Figure 6). High densities were often identified in July under the notification program. The 1998 geometric index for tautog (801) ranked well ahead of the previous high observed in 1989 (324) and represented the fourth straight year of increasing abundance. The arithmetic index for tautog (1,647) also ranked well ahead of the previous high (800) recorded in 1980. The geometric index for cunner (4,742) ranked ahead of the previous high recorded in 1981 (3,828) while the arithmetic index (17,518) ranked second behind 1981 (25,901). Current stock size data for cunner are not available but tautog are believed to be overfished and at very low levels (NFSC 1996). Perhaps two seasons of relatively high larval abundance will result in one or two strong year classes which will help rebuild the local stock.
- Larval radiated shanny were relatively abundant during the 1998 season. The annual geometric mean index of 554 ranked fourth over the 18-year time series dating back to 1981 and the arithmetic index ranked second dating back to 1975. In general shanny have been abundant in PNPS collections since 1989. Since this is a small, rather inconspicuous bottom fish, relatively little is known of its habits and data are not available concerning population trends.
- Larval winter flounder densities were relatively high throughout their occurrence period in 1997 and again in 1998. In 1997 larvae were particularly abundant in April and May while in 1998 they were particularly abundant in May and June. The annual geometric mean curve index for 1998 (1271) was exceeded only by that for 1997 (1800). Owing to three large densities in late May, early June ranging from 283 to 814 larvae per 100 m^3 water (see Table 3), the 1998 arithmetic curve area was considerably greater than the geometric index and in fact exceeded all previous years dating back to 1975 (Figure 6).

Larval winter flounder abundance in the Mount Hope Bay section of Narragansett Bay was average to somewhat below average in 1997 (40^{th} and 50^{th} percentile by two abundance indices) while in Niantic Bay, Connecticut, abundance was relatively high (2nd out of 15 years; Dale Miller, Northeast Utilities Service Co., personal communication). In spite of the differences in 1997 between these areas, in general larval flounder abundance has been found to be correlated between these two locations (NUSCO 1997), suggesting that widespread regional signals exist. For the 1975 through 1998 period no comparable correlation was detected between Mount Hope Bay and PNPS larval flounder abundance (Pearson correlation coefficient, $r = -0.196$, $p = 0.359$). Since Cape Cod appears to serve as a faunal barrier (see for example Anraku 1964, Davis 1984, Scherer 1984), regional signals may dissolve or weaken across that barrier. Stock abundance based on the Massachusetts Division Of Marine Fisheries spring, northern stock assessment appears to have been relatively stable since 1988. From that time through 1997 trawl estimates have varied without trend from 10 to 15 kg per tow, down from a high of 29 per tow in 1983. There is no evidence in that time series to suggest why particularly large numbers of larvae would be present in PNPS waters in 1997 and 1998. Hopefully the high larval abundance will result in production of a strong year class although this is unlikely to be observed until they recruit to trawl surveys.

Figure 5. Geometric mean monthly densities per 100 m³ of water in the PNPS discharge canal for the eight numerically dominant egg species and total eggs, 1998 (bold line). Solid lines encompassing shaded area show high and low values over the 1981-1997 period.

Brevoortia tyrannus

Gadidae-*Glyptocephalus*

Enchelyopus-Urophycis
Peprilus

Prionotus spp.

Labridae-*Pleuronectes*

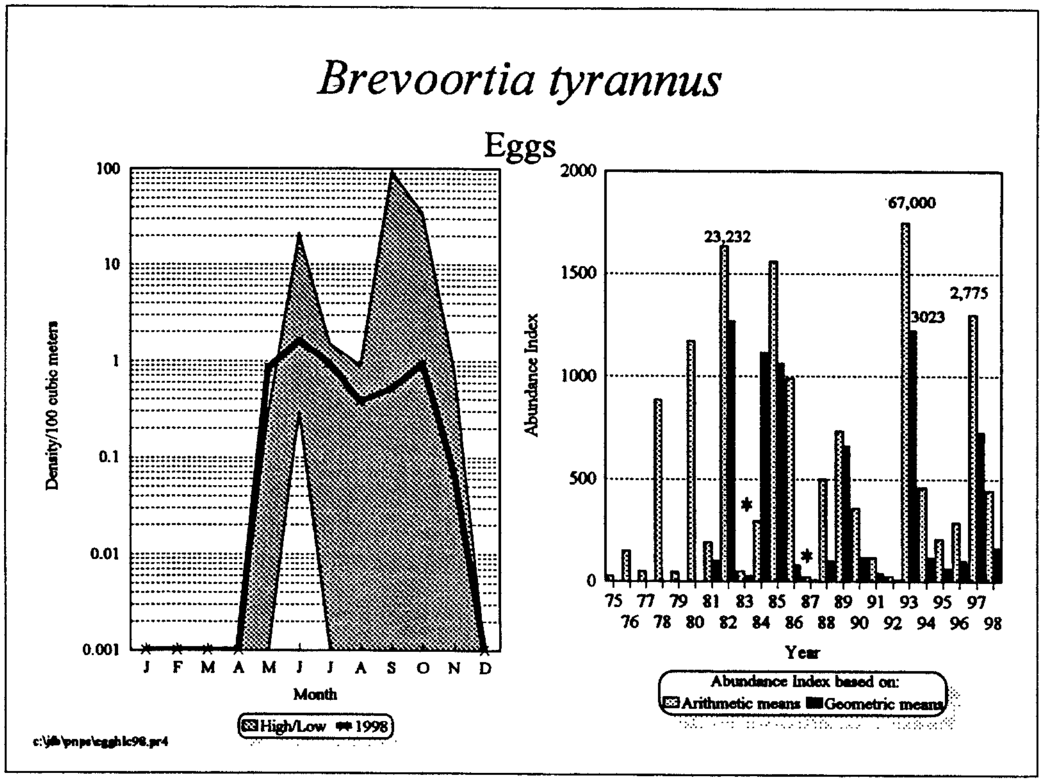
Scomber scombrus

Paralichthys-Scophthalmus

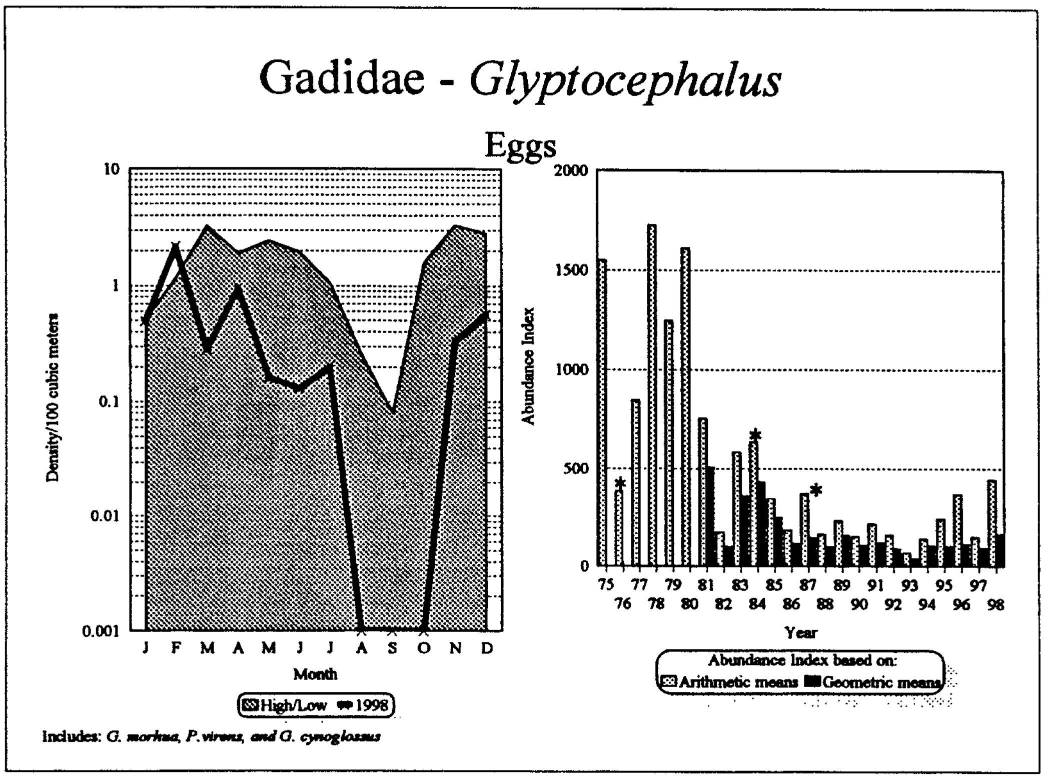
Hippoglossoides platessoides

Total eggs

To the right are plotted integrated areas under the annual entrainment abundance curves for 1975-1998. An asterisk above 1984 and 1987 marks the two years when values may have been low due to low through-plant water volumes from April-August. An asterisk above 1976 indicates abundance value may be low due to absence of sampling during January-late April; see text for clarification. Light bars represent indices based on monthly arithmetic means, solid bars (1981-1998) indices based on monthly geometric means.

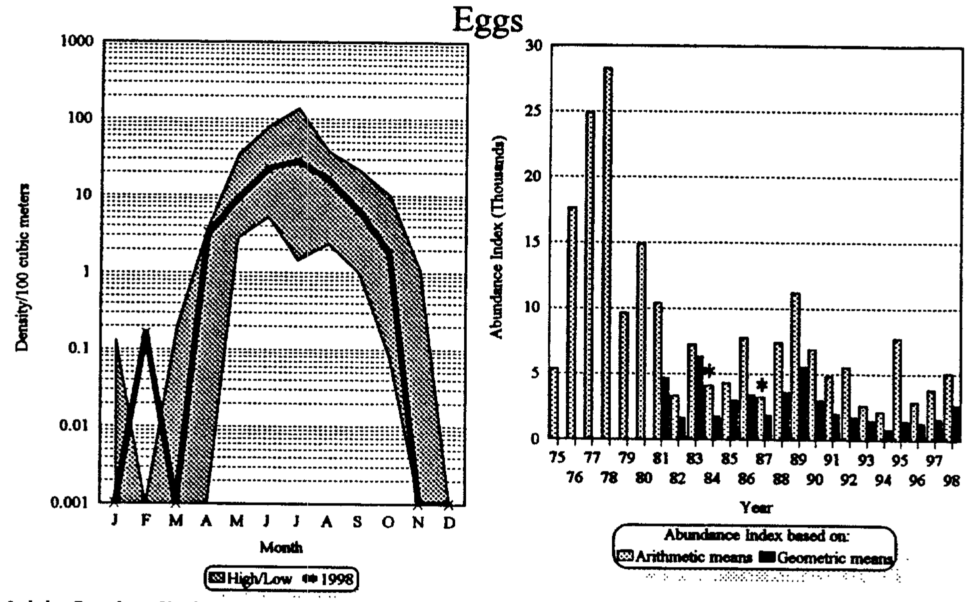


Brevoortia tyrannus
Eggs
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
c:\jdb\pnps\egghk98.pr4
Abundance Index
2000
1500
1000
500
0
23,232
67,000
2,775
3023
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means



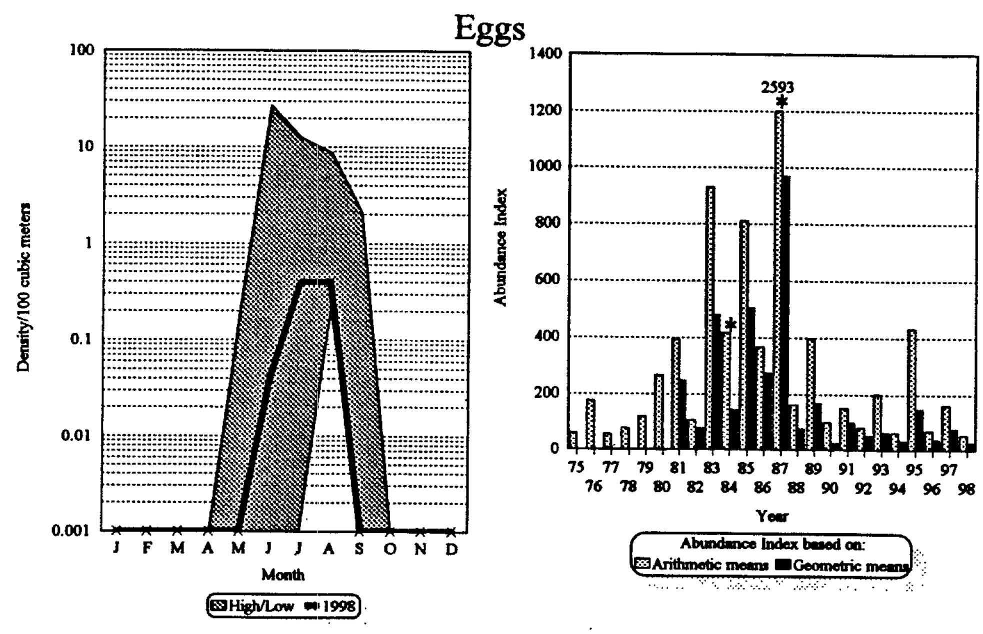
Gadidae - Glyptocephalus
Eggs
Density/100 cubic meters
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Includes: G. morhua, P. virens, and G. cynoglossus
Abundance Index
2000
1500
1000
500
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means

Enchelyopus - Urophycis - Peprilus

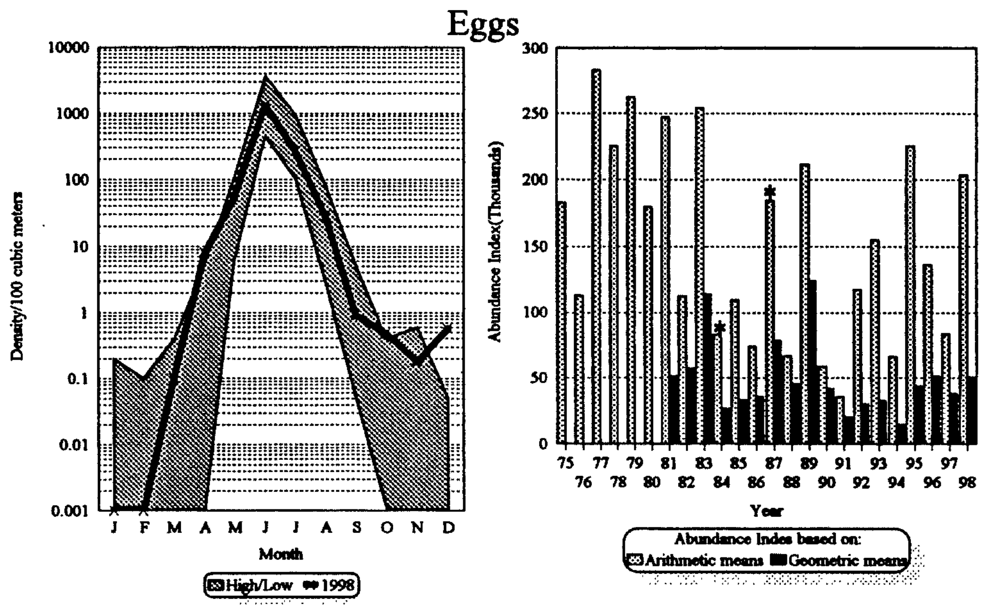


Includes: *E. cimbrius*, *Urophycis spp.*, and *P. triacanthus*

Prionotus spp.

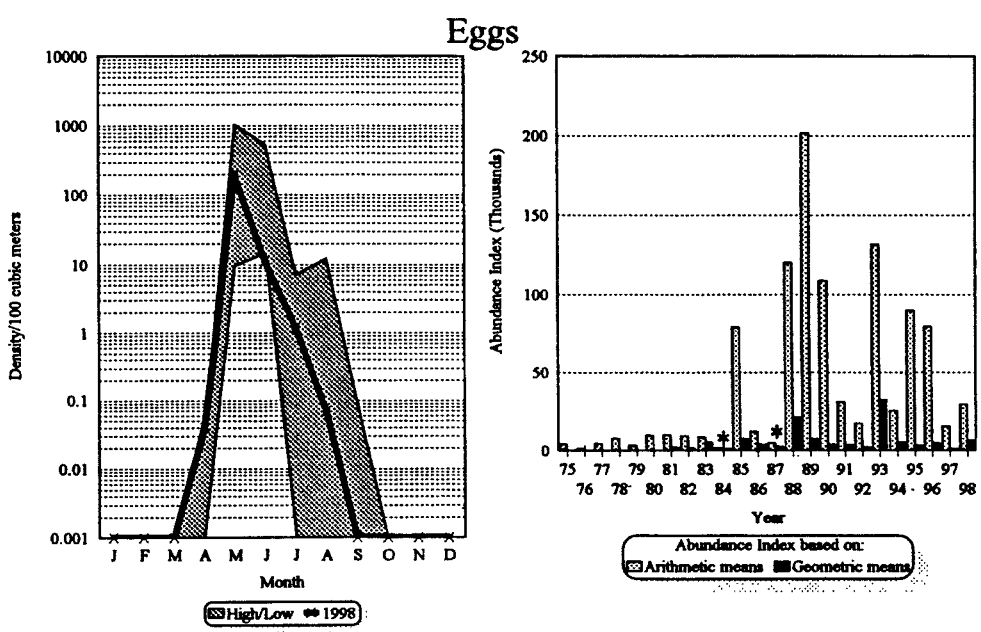


Labridae - *Pleuronectes*

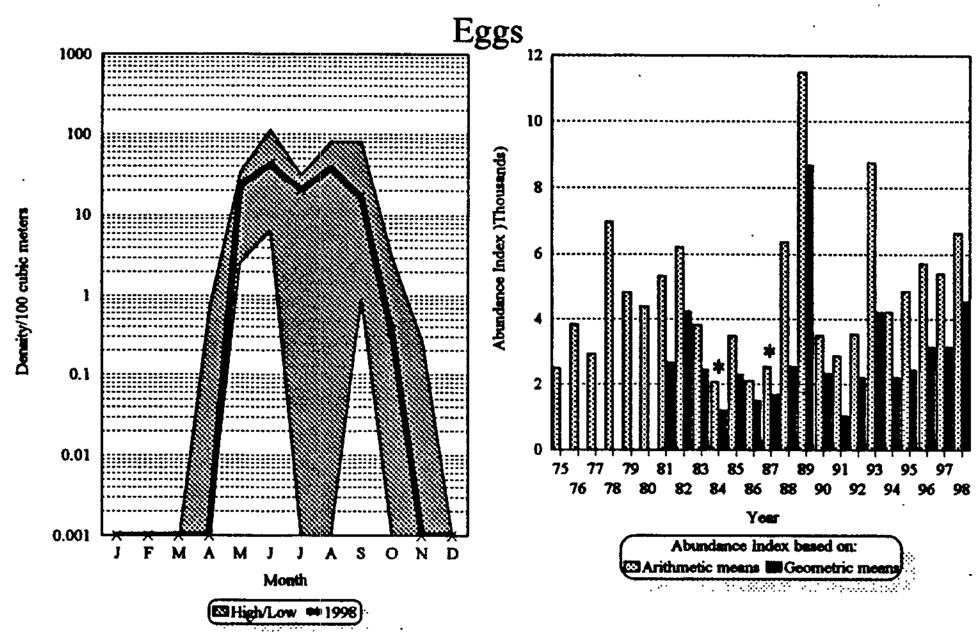


Includes Labridae and *P. ferrugineus*

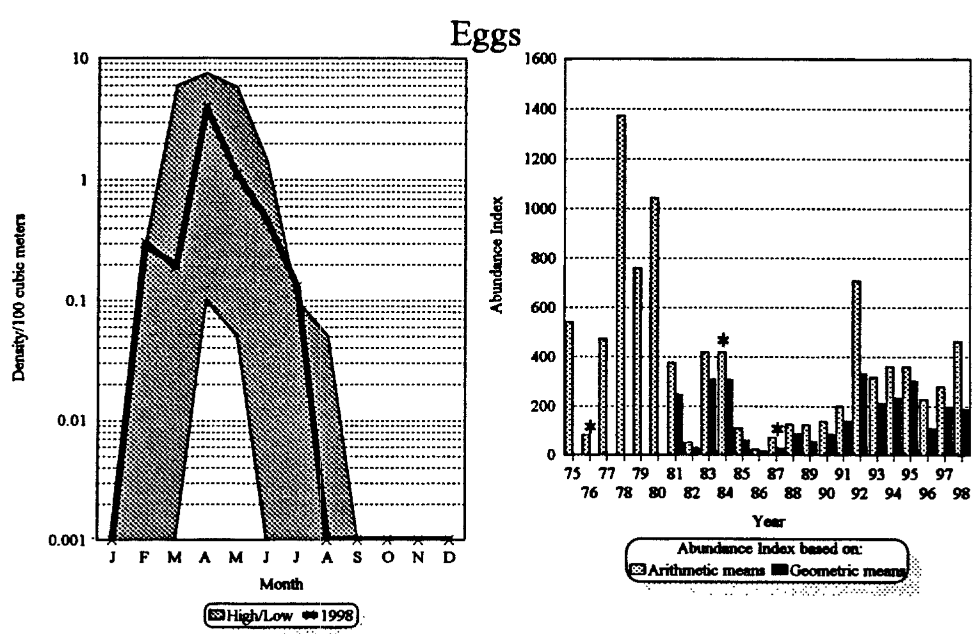
Scomber scombrus



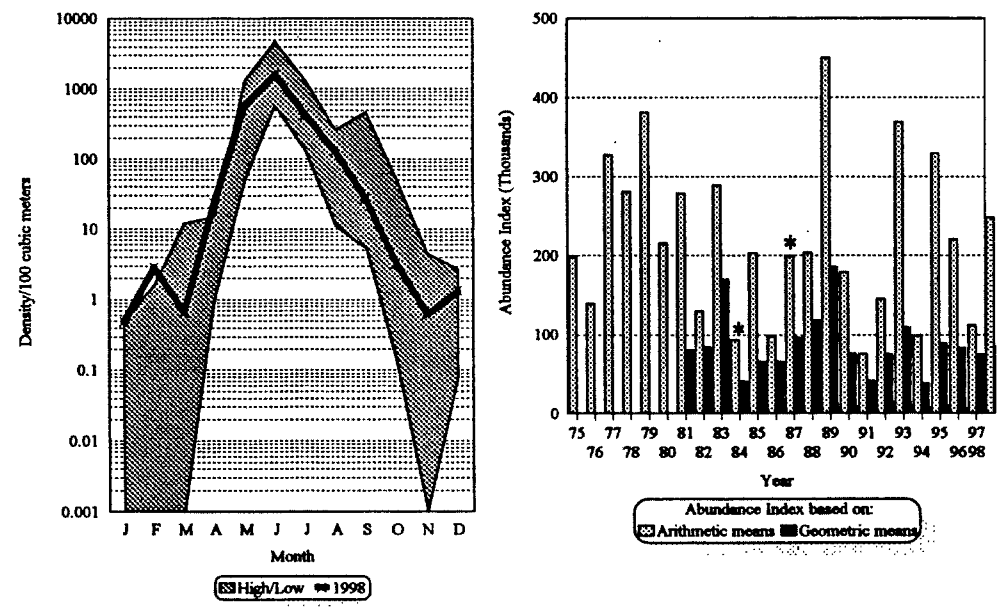
Paralichthys - Scophthalmus



Hippoglossoides platessoides



Total Eggs



10000
1000
100
10
1
0.1
0.01
0.001
Density/100 cubic meters
J F M A M J J A S O N D
Month
High/Low 1998
500
400
300
200
100
0
Abundance Index (Thousands)
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 9698
Year
Abundance Index based on:
Arithmetic means Geometric means

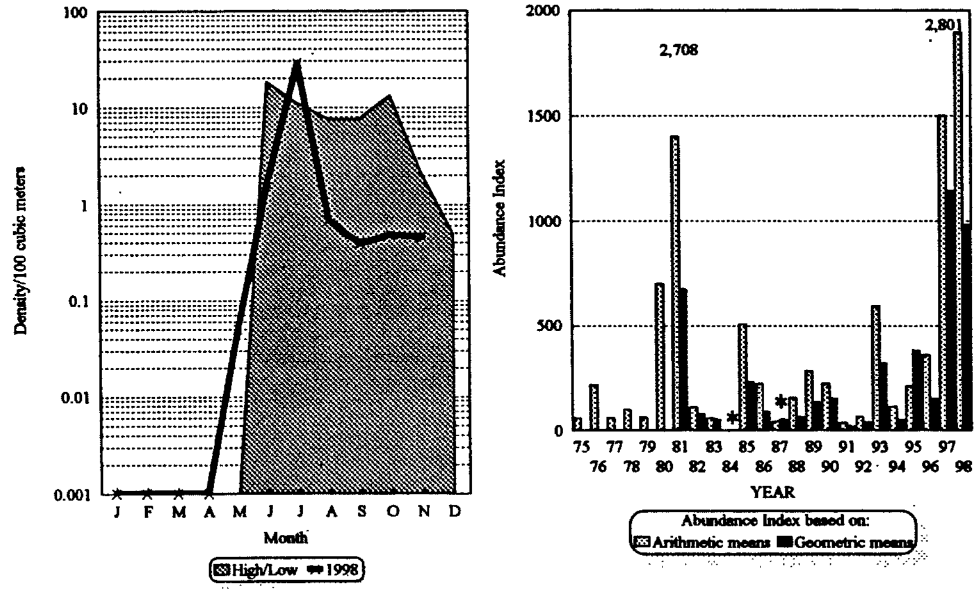
Figure 6. Geometric mean monthly densities per 100 m³ of water in the PNPS discharge canal for the thirteen numerically dominant larval species and total larvae, 8(bold line). Solid lines encompassing shaded area show high and low values over the 1981-1997 period.

Brevoortia tyrannus	*Tautogolabrus adspersus*
Clupea harengus	*Ulvaria subbifurcata*
Enchelyopus cimbrius	*Pholis gunnellus*
Urophycis spp.	*Ammodytes* sp.
Myoxocephalus spp.	*Scomber scombrus*
Liparis spp.	*Pleuronectes americanus*
Tautoga onitis	Total larvae

To the right are plotted integrated areas under the annual entrainment abundance curves for 1975-1998. An asterisk above 1984 and 1987 marks the two years when values may have been low due to low through-plant water volumes from April-August. An asterisk above 1976 indicates abundance value may be low due to absence of sampling during January-late April; see text for clarification. Light bars represent indices based on monthly arithmetic means, solid bars (1981-1998) indices based on monthly geometric means.

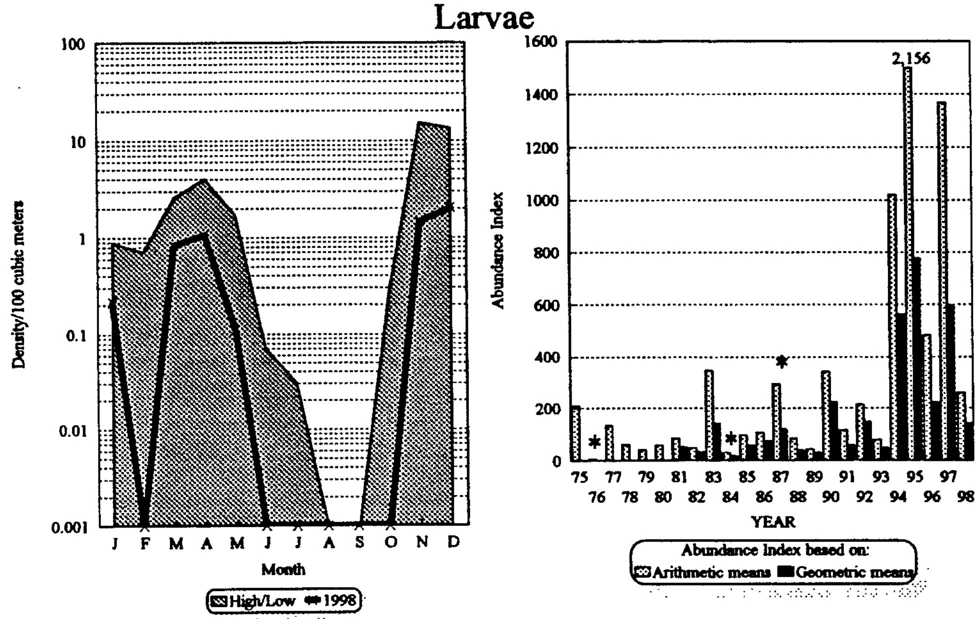
Brevoortia tyrannus

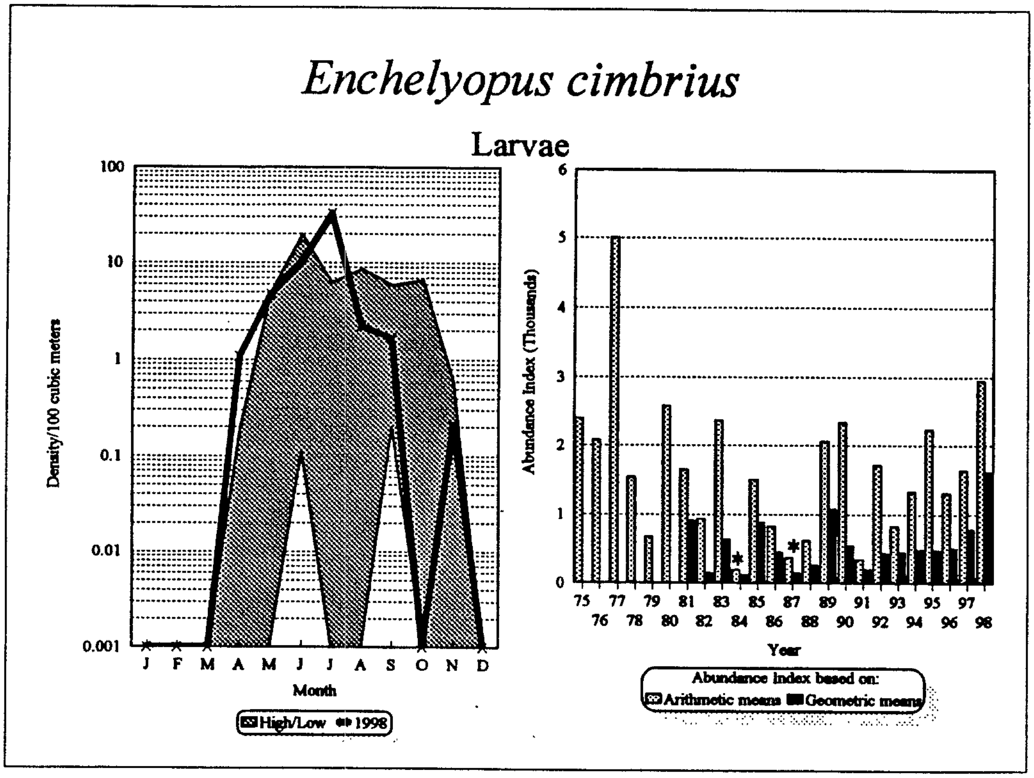
Larvae



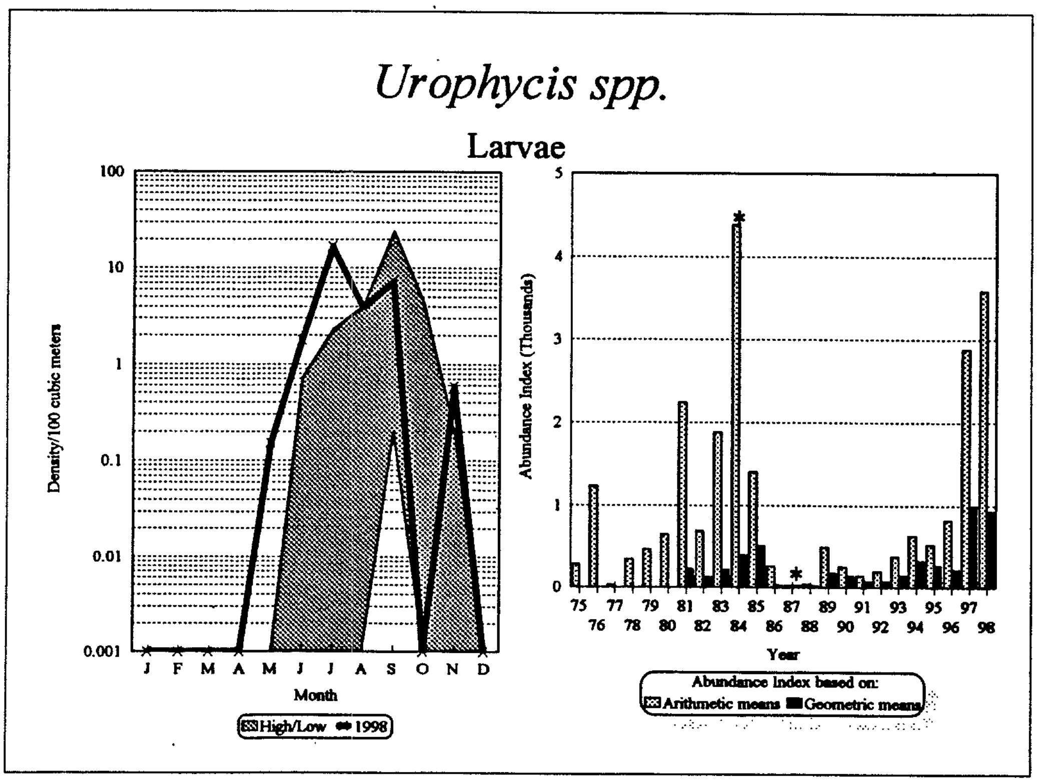
Clupea harengus

Larvae

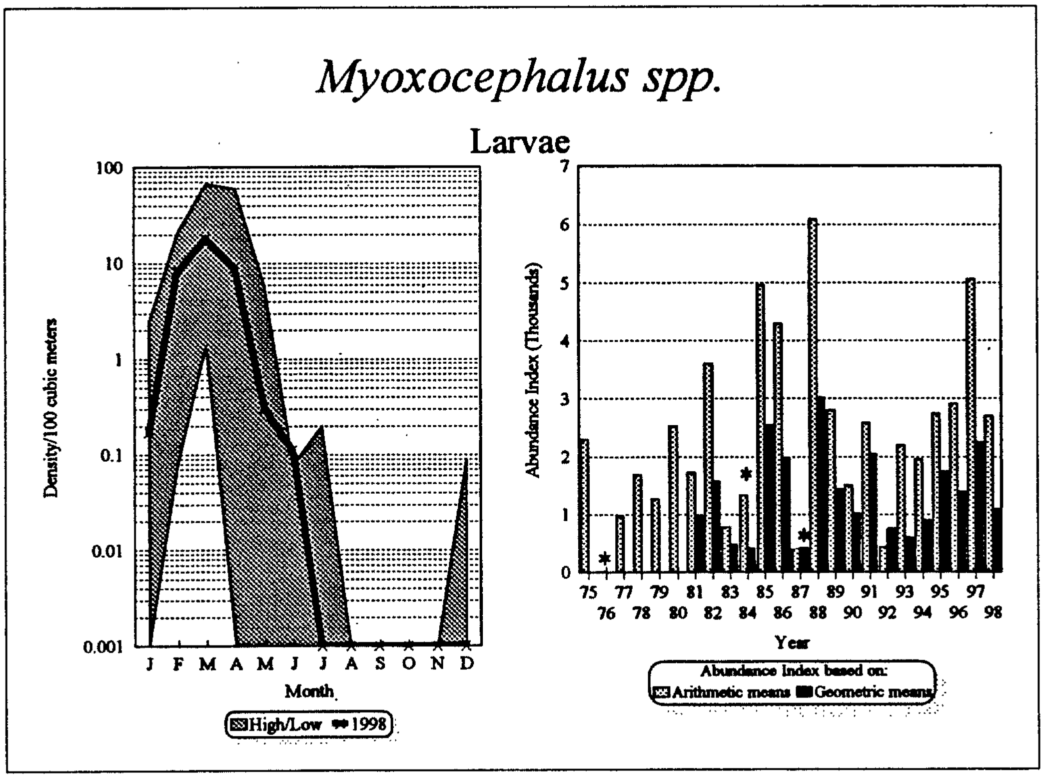


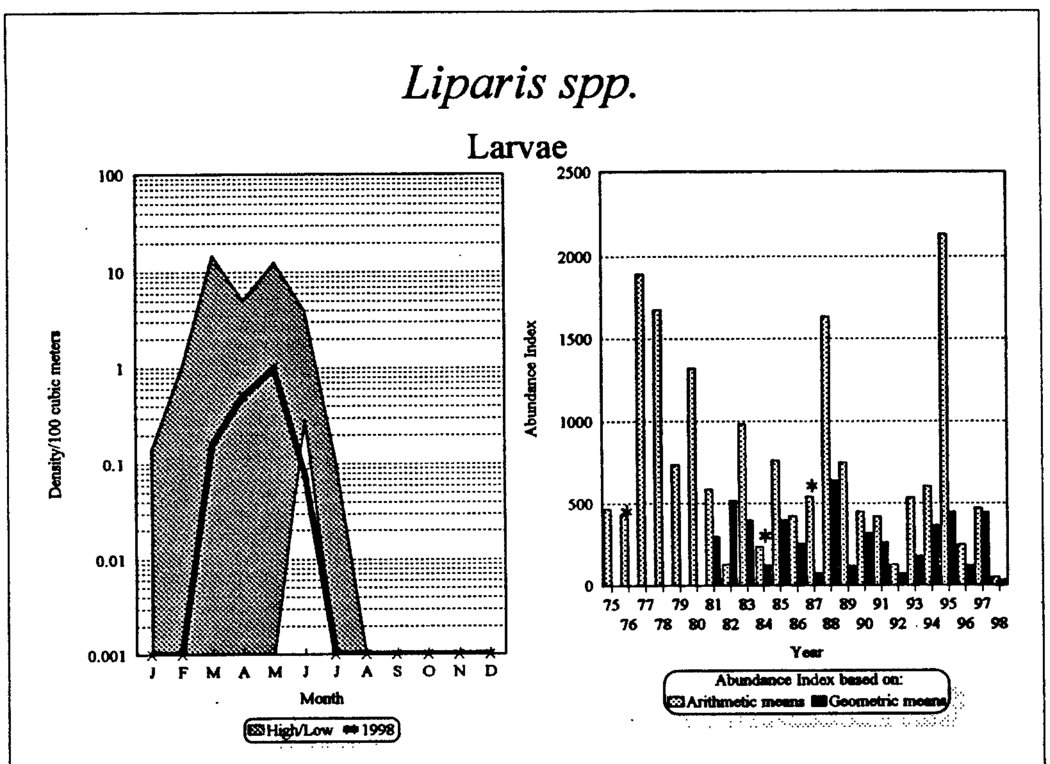


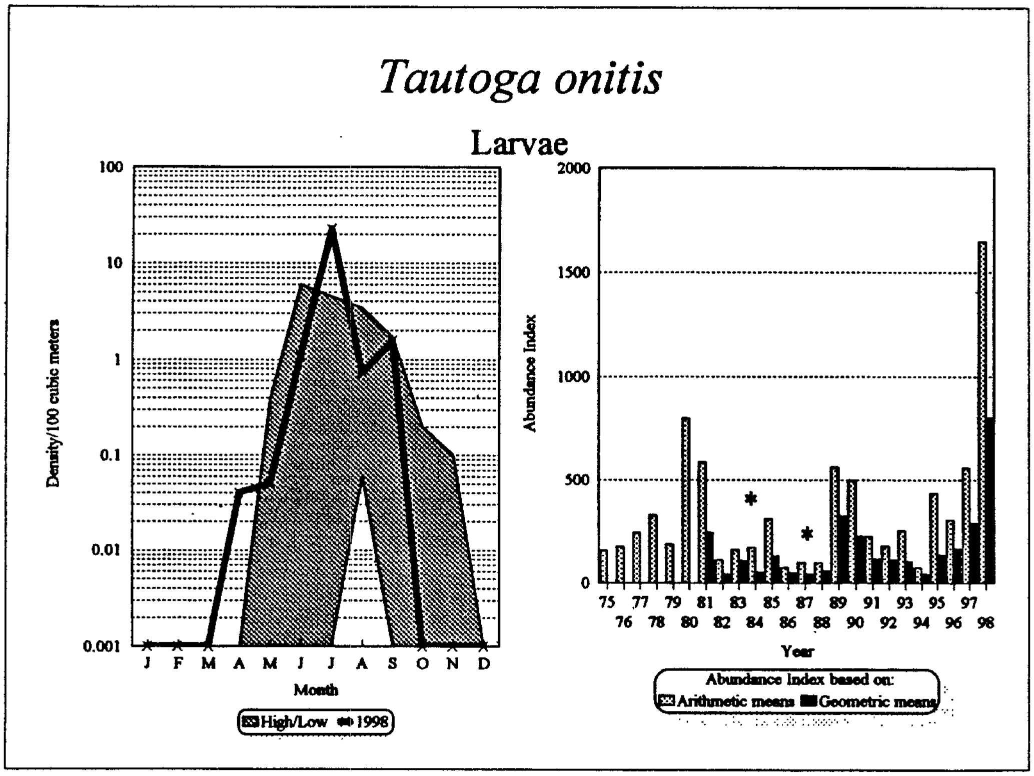
Enchelyopus cimbrius
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Abundance Index (Thousands)
6
5
4
3
2
1
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means



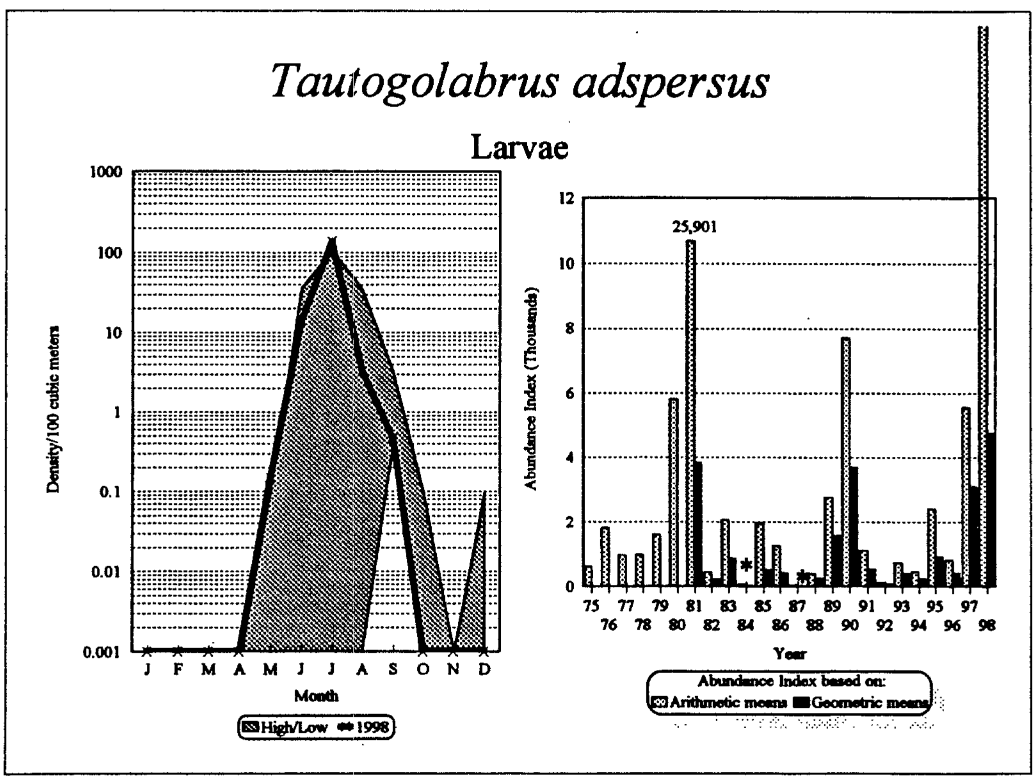
Urophycis spp.
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Abundance Index (Thousands)
5
4
3
2
1
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means


Myoxocephalus spp.
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Abundance Index (Thousands)
7
6
5
4
3
2
1
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means


Liparis spp.
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Abundance Index
2500
2000
1500
1000
500
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means



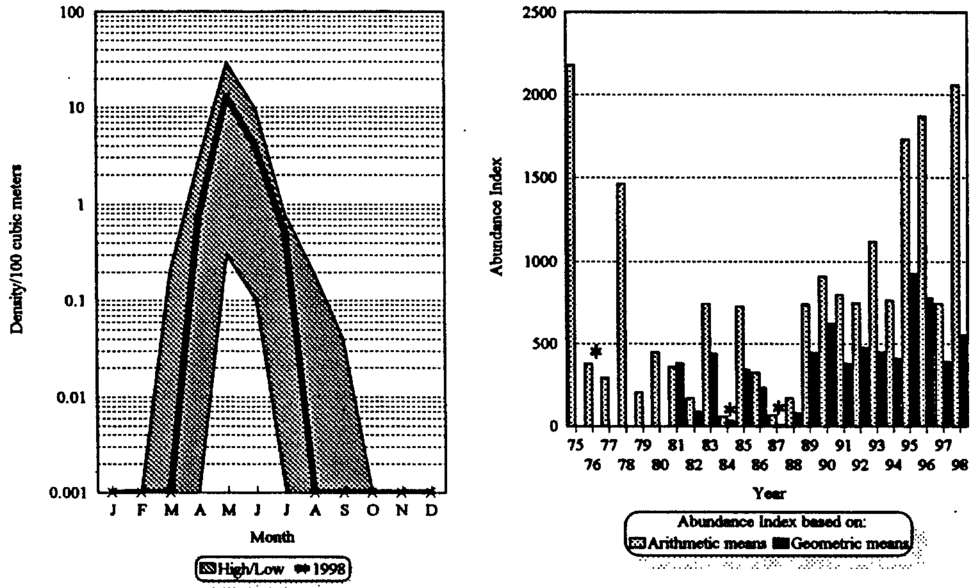
Tautoga onitis
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Abundance Index
2000
1500
1000
500
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means



Tautogolabrus adspersus
Larvae
Density/100 cubic meters
1000
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Abundance Index (Thousands)
25,901
12
10
8
6
4
2
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means

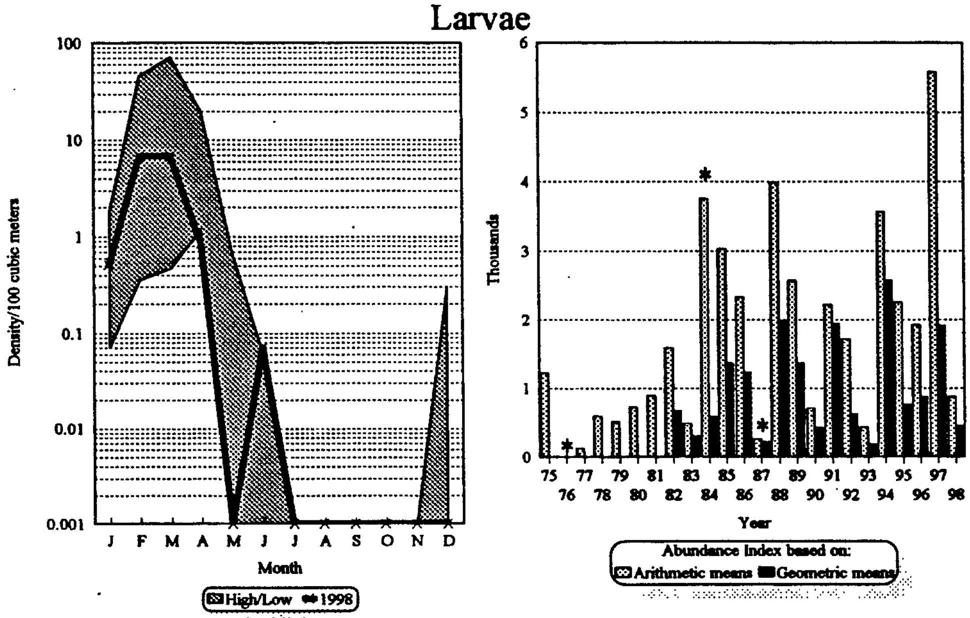
Ulvaria subbifurcata

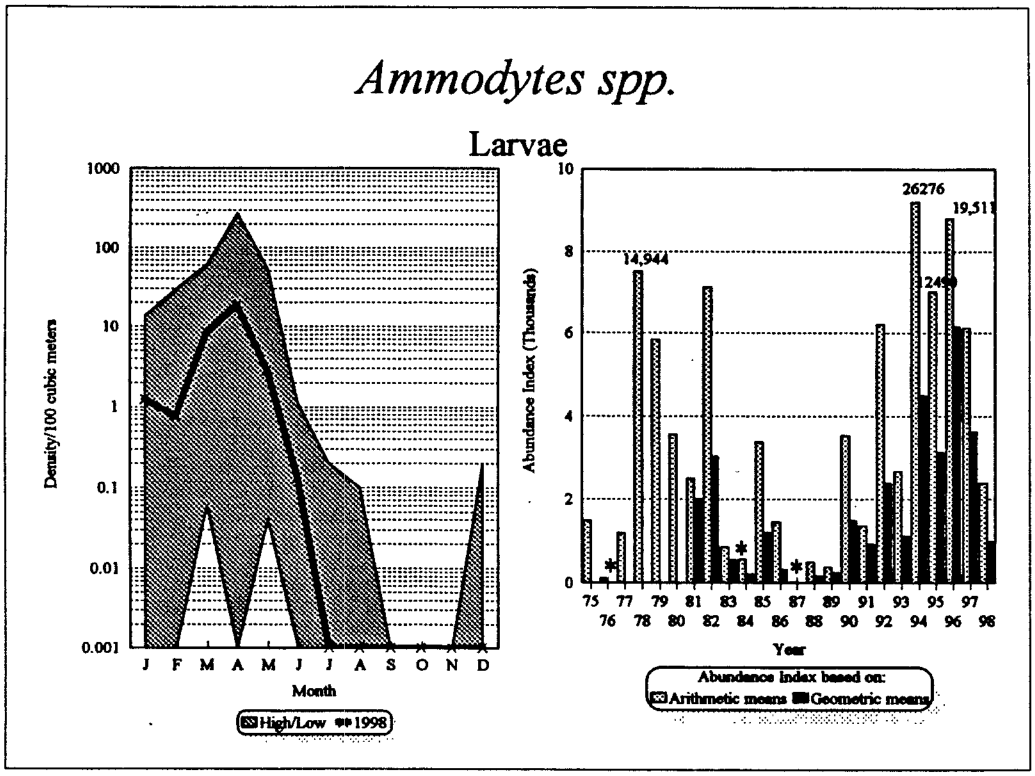
Larvae

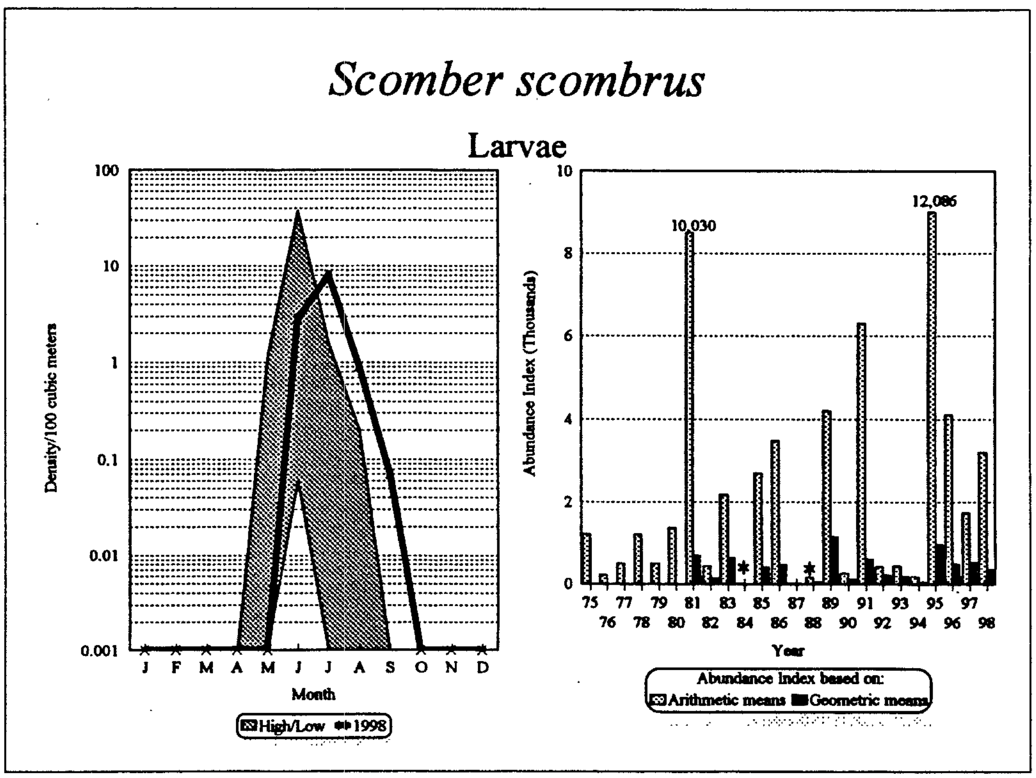


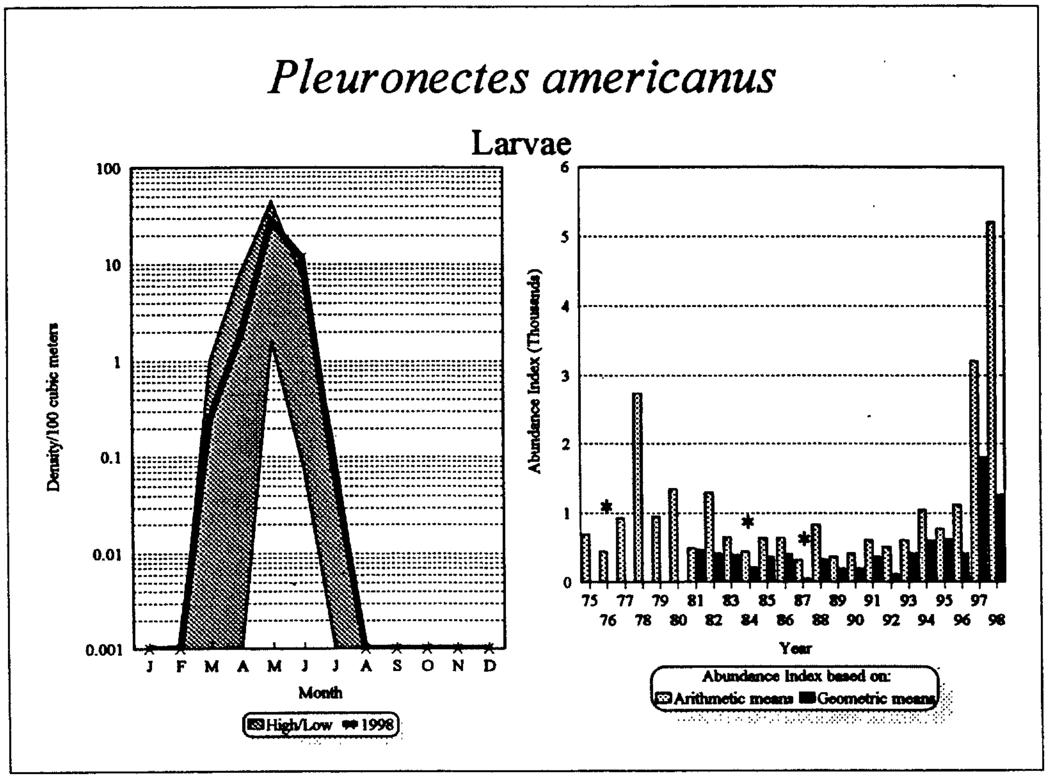
Pholis gunnellus

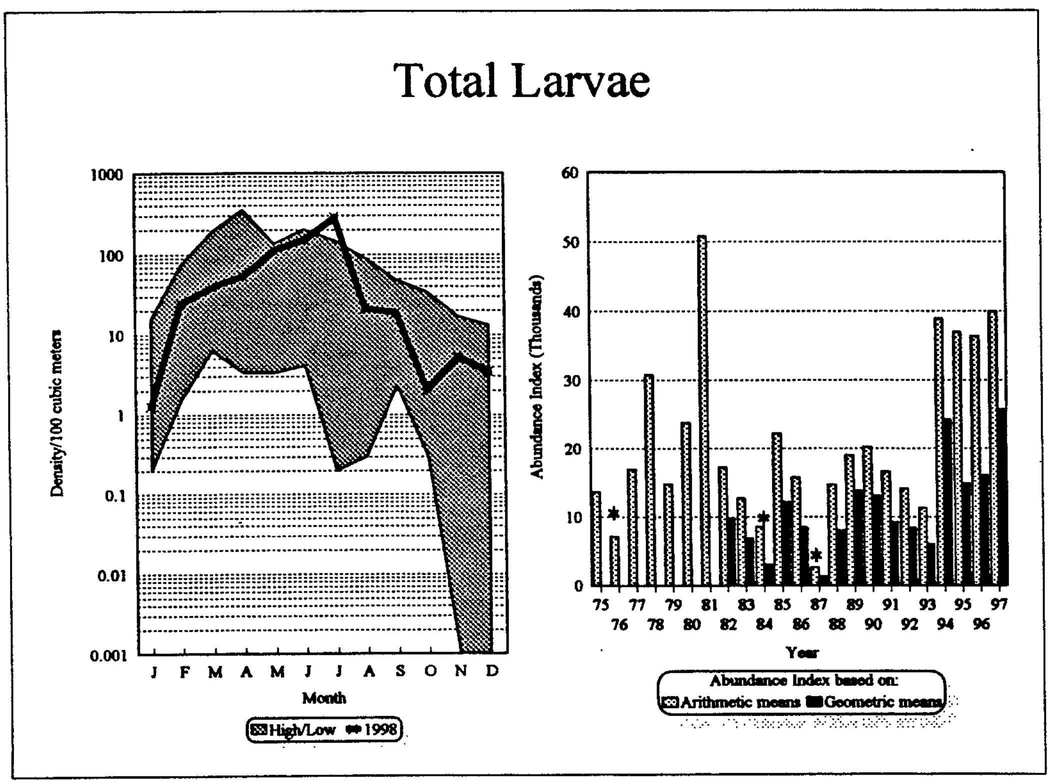
Larvae




Ammodytes spp.
Larvae
Density/100 cubic meters
Month
High/Low 1998
Abundance Index (Thousands)
Year
14,944
26276
19,511
Abundance Index based on:
Arithmetic means Geometric means


Scomber scombrus
Larvae
Density/100 cubic meters
Month
High/Low 1998
Abundance Index (Thousands)
Year
10,030
12,086
Abundance Index based on:
Arithmetic means Geometric means


Pleuronectes americanus
Larvae
Density/100 cubic meters
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Abundance Index (Thousands)
6
5
4
3
2
1
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96 98
Year
Abundance Index based on:
Arithmetic means Geometric means


Total Larvae
Density/100 cubic meters
1000
100
10
1
0.1
0.01
0.001
J F M A M J J A S O N D
Month
High/Low 1998
Abundance Index (Thousands)
60
50
40
30
20
10
0
75 77 79 81 83 85 87 89 91 93 95 97
76 78 80 82 84 86 88 90 92 94 96
Year
Abundance Index based on:
Arithmetic means Geometric means

D. Ichthyoplankton Entrainment Impacts - General

Ichthyoplankton entrainment at PNPS represents a direct negative environmental impact since fish eggs and larvae passing through the station are subjected to elevated water temperatures, shear forces, and periodic chlorination. In effect PNPS operates as a mechanical predator increasing overall mortality rates in western Cape Cod Bay. When PNPS is not on line, elevated temperature is not a factor but fish eggs and larvae may still be subjected to mechanical forces and periodic chlorination when circulating seawater or salt service water pumps operate. Although survival has been demonstrated for some species of fish eggs at PNPS such as the labrids (45%; MRI 1978) and winter flounder (73%, n = 11;MRI 1982) and among larvae at other power plants (0-100% initial survival depending on species and size; Ecological Analysts 1981), entrainment mortality is conservatively assumed to be 100% in all PNPS assessments.

To place fish egg and larval densities recorded in the PNPS discharge canal, expressed as numbers per 100 m^3 of water, in some perspective in relation to amounts of water utilized by PNPS, they were multiplied by maximum plant flow rates over each respective period of occurrence. This was completed for each of the numerically dominant species as well as total eggs and total larvae. Mean monthly densities were multiplied by 17,461.44, the full load flow capacity of PNPS in 100 m^3 units per 24-hour day, then by the number of days in each respective month they were collected. Values for each month in which a species or species group occurred were then summed to arrive at a seasonal entrainment value in each case (Figures 7 and 8). For cunner, mackerel, and winter flounder, egg and larval totals were calculated using individual densities and mesh adjustment where appropriate as part of an adult equivalent analysis (see next section). Among the eight numerically dominant groups, numbers of eggs entrained ranged from 918,500 for searobins (*Prionotus* spp) to 4,341,665,000 for the labrids. Corresponding values among the thirteen numerically dominant larval species varied from a low of 831,000 for seasnail to a high of 370,217,000 for cunner. For all eggs and all larvae combined, values amounted to 5,124,176,000 and 882,183,000 respectively. These totals state the extent to which large quantities of eggs and larvae can be entrained by the circulating seawater system at PNPS during a single year; based on the assumption of 100% mortality all are lost to the local population.

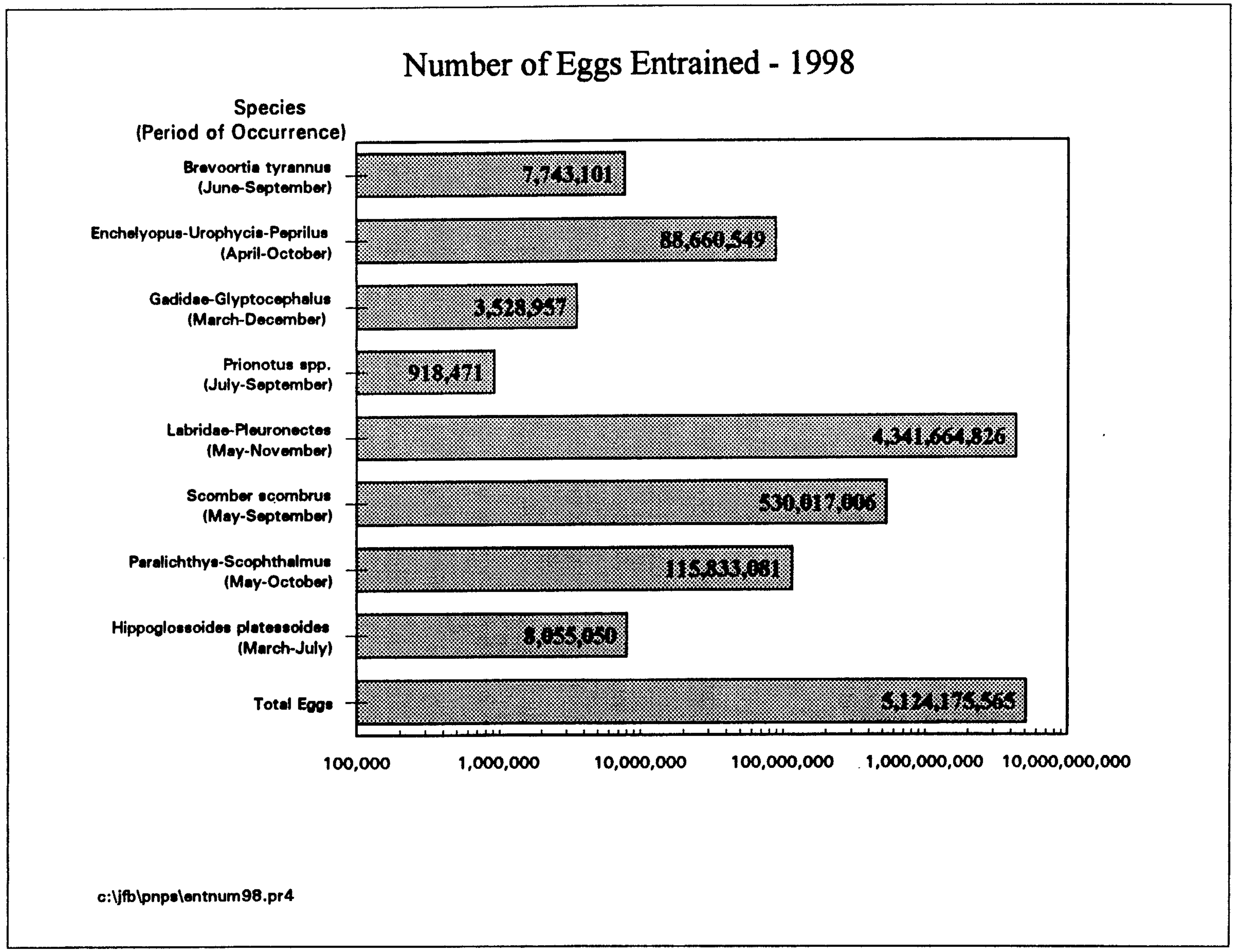


Figure 7. Estimated numbers of fish eggs entrained at PNPS, by species or group, 1998.

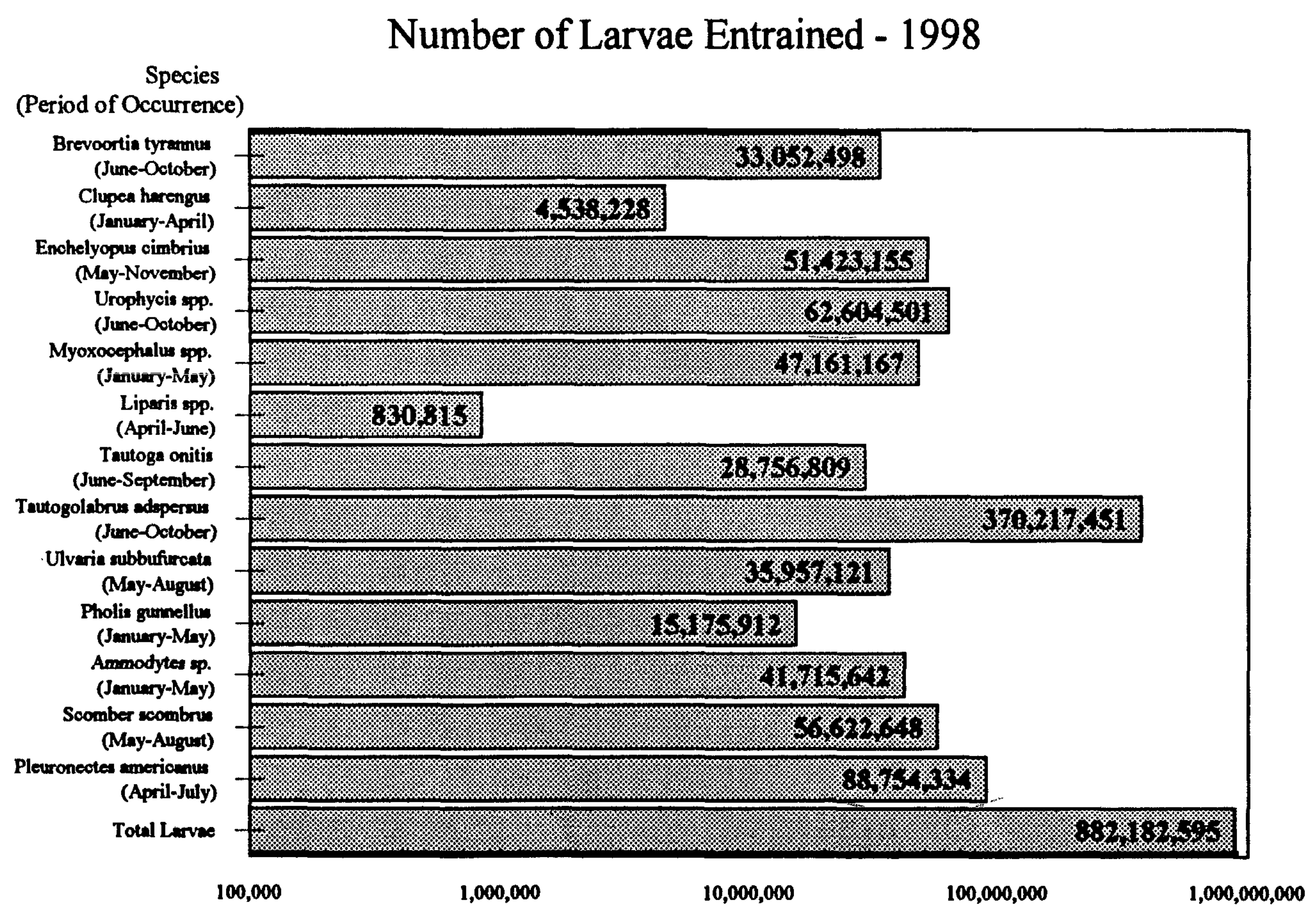


Figure 8. Estimated numbers of fish larvae entrained at PNPS, by species or group, 1998.

E. Ichthyoplankton Entrainment - Specific

Estimated numbers of eggs and larvae entrained annually at PNPS were examined in greater detail for three species of fish using the equivalent adult procedure (EA, see Horst 1976, Goodyear 1978, for example). Somewhat arbitrarily this review dates back to 1980 so that with the addition of 1998, 19 years are included. The adult equivalent methodology applies estimated survival rates to numbers of eggs and larvae lost to entrainment to obtain a number of adult fish which might have entered the local population had entrainment not occurred. The consequences, if any, of the loss can then be considered if the size of the extant population is known or numbers can be compared with commercial or recreational landings.

Many assumptions are associated with the EA procedure. The fish population is assumed to be in equilibrium, therefore in her lifetime each female will replace herself plus one male. It is also assumed that no eggs or larvae survive entrainment and that no density-dependent compensation occurs among non-entrained individuals. The later two assumptions result in an overestimation of plant impacts. As pointed out earlier, numbers of eggs and larvae entrained were determined using the full-load-flow capacity of the plant. This value was used even if the station was out of service and less than full capacity was being circulated. In those cases the adult equivalents are conservatively high.

Since plankton densities are notorious for deviating from a normal distribution but do generally follow the lognormal, geometric mean densities more accurately reflect the true population mean. For data which are skewed to the right such as plankton densities, the geometric mean is always less than the arithmetic mean (see Figures 5 and 6). In calculating total entrainment values for the adult equivalent methodology we chose to use the larger arithmetic mean for all sampling dates preceding April 1994 when three replicate samples were taken per sampling occasion to lend additional conservatism to the assessments. Beginning with April 1994 each individual sample density was utilized so that no averaging was necessary.

In summary, four opportunities were chosen to overestimate the impact of PNPS

- All eggs and larvae were assumed killed by plant passage regardless of thermal load.
- No density-dependent survival compensation was assumed to occur.
- PNPS was assumed to operate at full-flow capacity year round.

- Mean entrainment densities were overestimated by the arithmetic mean for sampling dates when three replicates were taken.

The three species selected were winter flounder, cunner and Atlantic mackerel. Flounder were chosen because of their commercial and recreational value as well as their importance in PNPS ecology studies. Cunner were selected because they are abundant in entrainment samples and in the local area and PNPS finfish studies have been focusing on that species which appeared to be in a declining trend from 1980 to 1994 (Lawton et al. 1995). Mackerel were included because they are abundant among the ichthyoplankton entrained, both eggs and larvae being removed from the local population, and they are commercially and recreationally valuable.

Winter Flounder

The annual larval entrainment estimates were converted to equivalent numbers of age 3 adults, the age at which flounder become sexually mature (Witherell and Burnett 1993, NOAA 1995). Numbers of stage 1 and 2 larvae collected prior to 1995 were scaled upward by 1.62 to correct for mesh extrusion (MRI 1995). Two sets of survival values were used. The first set followed NEP (1978) using data from Pearcy (1962) and Saila (1976). Briefly, this consisted of dividing the total number of entrained larvae by 0.09 to estimate the number of eggs which hatched to produce that number of larvae. The number of eggs was then multiplied in succession by 0.004536, an estimate of survival from a newly hatched egg to day 26; 0.2995, survival from day 27 to metamorphosis; 0.03546, survival of juveniles from 3 to 12 months; 0.3491, survival from 13 to 24 months; and finally 0.33, survival from 24 to 36 months. The second approach followed larval stage-specific survival rates (S) derived by NUSCO (1993) as modified by Gibson (1993a). These are as follows:

S (stage 1) = 2.36E-01
S (stage 2) = 1.08E-01
S (stage 3) = 1.54E-01
S (stage 4) = 6.23E-01
S (age 0) = 7.30E-02
S (age 1) = 2.50E-01
S (age 2) = 4.77E-01

In using the stage-specific rates it is recognized that NUSCO employs different morphological stage criteria than those used at PNPS (NUSCO 1998). However a comparison of samples from both studies showed stages to be quite comparable until larvae approach metamorphosis, a size not often collected because these individuals begin to assume a benthic life style. Although small numbers are entrained each year, flounder eggs were ignored because they are demersal and adhesive and not generally impacted by entrainment.

Recently Rose et al. (1996) presented information on a population dynamics model for winter flounder consisting of separate young-of-the-year and adult components. The young-of-the-year model includes survival rates for eggs, larvae, early and late juveniles stages. Since the model is designed to mathematically represent numbers of individuals as they develop from one stage to another, it is difficult to apply their survival rates to the mixed age pool of larvae entrained at PNPS. All individuals would need to be converted to a common starting point such as newly hatched eggs as is done with the unstaged approach. By using a value of 0.09 to step back from mixed-age larvae to hatched eggs, the rates utilized by Rose et al. produce approximately twice as many fish as the staged survival values provided above. Since the staged survival values were adjusted by Gibson (1993a) to provide an equilibrium population the Rose et al. values likely overestimate EA values in this instance.

The general, unstaged larval survival values produced an adult equivalent value of 5,473 age 3 fish for 1998 (Figure 9, Table 5). The stage-specific values produced an EA total about fourteen times higher at 77,428 age 3 individuals. Based on a weight of 0.6 pounds per fish (Gibson 1993b), these values convert to 3,284 and 46,457 pounds, respectively. Comparable values for 1980 -1997 ranged from 535 to 3,414 fish (mean = 1,397 fish, 838 pounds) for the general approach and 2,624 to 47,087 (mean = 10,601 fish, 6,361 pounds) for the staged approach. EA totals for 1984 and 1987 were omitted here because both circulating seawater pumps were off for most of the larval winter flounder seasons during protracted maintenance outages. There is some indication that ichthyoplankton entrainment is disproportionately low when only the salt service water pumps are in operation (MRI 1994). Values for 1998 using the unstaged general approach represented the second consecutive record high year exceeding the notably high value for 1997 (3,414 fish) by 60%. Values based on the staged approach also exceeded the previous high recorded in 1997 (47,087) by 64%. The relatively high EA values noted in 1998 are directly attributable to the unusually high number of larvae entrained. The large differences between the two sets of survival estimates clearly show how relatively small variations in survival values when applied to large numbers of larvae can result in relatively large variations in adult numbers (see Vaughan and Saila 1976 for example).

Over the 1982 through 1997 period an annual average of 1,557,365 pounds (s.e. = 275,125 pounds) of flounder were landed commercially from NOAA statistical area 514 which covers Cape Cod Bay and Massachusetts Bay (Table 6). Based on a weight of 0.6 pounds per fish, the average estimated loss of 685 or 6,361 pounds of equivalent adults from PNPS entrainment over a similar time frame represents 0.04 or 0.4% of those landings. Area 514 commercial landings declined sharply after 1993 from1,057,211 pounds that year to 16,788 pounds in 1995 and only 1,798 pounds in 1997 (Table 6). The precipitous drop is attributable to increased fishing restrictions and stock declines. EA values for 1994 through 1998 alone appear quite high compared to the reduced commercial landings and in fact the unstaged values for both 1997 and 1998 exceed the commercial landings for 1997.

Winter flounder also have considerable value as a recreational species. Based on NOAA records[3] an annual average of 978,255 fish (s.e. = 317,368) weighing an average of about one pound each were landed from Massachusetts inland waters over the 1981-1997 period (Table 6). More recently (1990 -1997) recreational landings have been well below earlier years because of stock declines and area closures consistent with commercial landings; an annual average of 120,253 fish (s.e. = 11,722) were reported landed in the state from inland waters during that more recent period. These fish were also apparently smaller, weighing an average of 0.72 pounds each. Unfortunately these landings are compiled by state within distance from shore areas (inland, <3 miles from shore, > 3 miles from shore) and the number of fish taken from a more appropriate area such as Cape Cod Bay are not available. Arbitrarily adding 20,000 pounds of recreationally-caught flounder to the 1994-1997 Area 514 commercial landings would bring the respective totals for those four years to 348,706, 36,788, 22,961 and 21,798 pounds. The PNPS entrainment EA values from the unstaged approach for those years then amount to 0.2, 1.4, 3.0, and 9.4%, respectively. The 1998 unstaged estimate of 3,284 pounds represents 15% of the 1997 landings estimate. For the staged larvae approach the four values range from 2.1 to 130%, respectively with the 1998 value of 46,457 pounds representing more than twice the 1997 landings estimate. Clearly the decline in commercial landings after 1994 suggest that those values are no longer a realistic measure of PNPS EA losses.

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[3] Recreational landings data were obtained via the internet at http://remora.ssp.nmfs.gov/mrfss.

Massachusetts Division of Marine Fisheries (DMF) personnel made estimates of the number of adult winter flounder (>280 mm TL - age 3+) in a 106 square mile area in the vicinity of PNPS using area swept by a commercial trawl and using several mark and recapture models in 1997 and 1998 (see Section IIIA, this report). While reliable estimates of local population size are difficult to make, they can provide realistic numbers with which to compare EA values. Landings data typically represent numbers caught over a very large area or as displayed by the most recent commercial landings can be subject to catch restrictions or changes in fishing effort which make them less useful. The DMF area swept estimate equaled 321,832 adults based on gear efficiency of 50% with confidence limits ranging from 271,000 to over 373,000 fish. DMF's mark-and-recapture study was limited by disappointing tag returns. Estimates ranged from 115,000 to 520,000 adults depending on the model employed. EA estimates for 1997 using the unstaged survival values amount to 1.1% of the area swept estimate and 3.0% of the low mark and recapture estimate. The 1997 EA estimate from the staged approach amounted to14.6% of the area swept estimate and 40.9% of the low-end mark-recapture estimate. Fewer fish were collected in 1998, providing a comparable area-swept estimate of 264,812 adults and best mark-recapture estimate of 104,429 fish (see Section IIIA). Comparing the 1998 unstaged EA estimate to these values provided proportional losses of 2.1 and 5.2%, respectively. The staged estimate amounted to 29.2 and 74.1%, respectively.

As mentioned earlier, two consecutive years of relatively high larval flounder entrainment at a time when local area stock size shows no sign of increasing remains unexplained.

Cunner

Goodyear's (1978) basic procedures were used to estimate equivalent adult values. This method converts numbers of eggs and larvae to numbers of fish at age of sexual maturity which occurs for approximately half the population at age 1 (P. Nitschke, University of Massachusetts, Amherst, personal communication).

Assuming all labrid eggs were cunner eggs in PNPS entrainment samples (Scherer 1984), cunner larva:egg ratios were determined from PNPS samples to provide an estimate of survival from egg to larva. Mesh correction values were first applied to both eggs and larvae. Presented in MRI (1998) these were 1.24 for eggs taken from 1980-1995, 1.14 for eggs taken in 1995, and 1.10 for eggs taken in 1997. The 1997 value was used for 1998. Larval cunner mesh values applied were 1.16 for stage 1 and 1.28 for stage 2, irrespective of year. From 1980 to 1998 the larva/egg ratio ranged from 0.001284 to 0.128812 and averaged 0.030480; 1984 and 1987 were excluded because of extended circulating seawater pump shutdown. Average lifetime fecundity was calculated from fish collected in the PNPS area by Nitschke (1997). He provided numbers of eggs produced at age in the second order form:

$$\text{Log } F = [2.891 \log A] - [1.355 \log A^2] + 3.149 \text{ where}$$

F = fecundity at age A

Age-specific instantaneous mortality necessary for calculation of average lifetime fecundity was calculated from fish trap collections made from 1992 - 1997 (Brian Kelly, Massachusetts Division Of Marine Fisheries, personal communication, MRI 1998). Average instantaneous mortality rates for the PNPS area collections from 1992 through 1997 using this approach were as follows:

Age 3 = 0.286	Age 7 = 0.653
Age 4 = 0.342	Age 8 = 1.463
Age 5 = 0.645	Age 9 = 0.728
Age 6 = 1.260	

Utilizing data from Serchuk and Cole (1974) for age 1 through 5 cunner collected with assorted gear, a survival rate of S = 0.605 was obtained (Z = 0.5025) which appears comparable to the PNPS values. Age 1 and 2 fish appeared less abundant in the PNPS collections than age 3 fish (MRI 1998), suggesting they were not fully recruited to the trap collections, perhaps due to their small size or behavior. Fish older than age 10 were rarely taken both because they are uncommon and because they can exceed the maximum size susceptible to the fish traps. In the absence of additional information an overall mean value of Z = 0.831 was substituted for age 2 and age 10.

Based on the PNPS area fecundity study (Nitschke 1997), 50% of age 1 females were assumed to be mature; complete recruitment was assumed by age 2. Following Goodyear (1978), an average lifetime fecundity of 21,656 eggs per female at age 1 was calculated (MRI 1998). Utilizing the survival estimate for eggs to larvae and average lifetime fecundity, a survival estimate for larvae to adult of 3.03E-3 was obtained. Converting numbers of eggs to larvae utilizing the larvae/egg ratio and then converting numbers of larvae to adult produced an estimate of 1,522,731 cunner potentially lost to entrainment effects in 1998. Comparable values for 1980-1997 ranged from 113,048 to 2,353,607 adults averaging 474,279 (s.e. = 119,048) over the 19-year period (Figure10, Table 7). The high value of 2,571,973 recorded in 1981, attributable to high egg and exceptionally high larval densities, skewed the mean EA value; without that high value a mean of 363,730 (s.e. = 46,855) was obtained.

Cunner have no commercial value and little recreational importance (although many may be taken unintentionally by shore fishermen) so that current landing records are not available. To shed some light on their abundance in the PNPS area, calculations were performed to estimate the number of adult cunner which would be necessary to produce the number of eggs found there. The PNPS area was defined by Cape Cod Bay sampling stations 2,3,4,7,8 (MRI 1978b), the half-tide volume of which was estimated by planimetry from NOAA chart 1208 at 22,541,000 100 m^3 units. Labrid egg densities were obtained at those stations on a weekly basis in 1975 and they were integrated over time (April-December) using the mean density of the five stations. The integrated values were multiplied by 1.40 to account for extrusion through the 0.505-mm mesh used in that survey (MRI unpublished data), then by the sector volume. Based on the 0.333/0.202-mm mesh data collected from the PNPS discharge stream from 1994 through 1997, additional upward scaling might be appropriate; however specific data for towed samples with 0.202-mm mesh are not available and an estimated value was not applied. Omitting this step likely led to an underestimate of the number of eggs produced and therefore to an underestimate of the number of adults spawning in the area. The resulting value was divided by 2.2, the estimated incubation time in days for cunner eggs (Johansen 1925), then divided by 30,230, an estimate of mean annual fecundity per female derived from Nitschke (1997) and MRI 1998). Lastly the resulting value was multiplied by 2 assuming an even sex ratio. These calculations resulted in an estimated production of 6.899E12 eggs by an estimated 207,473,000 adult fish. The loss of 1,522,731 adults in 1998 due to PNPS operation represents 0.7% of the estimated spawning stock. The annual mean loss of 529,461 fish, including 1981 and 1998, represents 0.26% of the stock estimate.

MDMF personnel have chosen cunner as an indicator species for PNPS impact investigations. Tagging studies were conducted during the 1994 and 1995 seasons to estimate the size of the cunner population in the immediate PNPS area. Minimum tagging size and therefore the minimum size fish enumerated was 90 mm TL. Estimates were highly localized since individual cunner have a very small home range measured on the order of 100 m^2 or less (Pottle and Green 1979). Estimated population size for the outer breakwater and intake areas combined were 7,408 and 9,300 for the two respective years. Combining upper 95% confidence limits produced totals of 10,037 and 11,696 fish, respectively. Since the upper confidence limit total is only 0.003% of the egg based population estimate, it is clear that eggs must arrive at PNPS from areas removed from the immediate vicinity of the Station. A hydrodynamic modeling study completed by Eric Adams of MIT (see also section III.A) predicted that 90% of the cunner eggs and larvae entrained at PNPS come from within about 5.5 miles of PNPS to the north down to White Horse Beach, about one mile to the south of PNPS. This area extends further to the north than the area 2,3,4,7,8 used in the above egg estimates. The number of eggs entrained indicate that cunner must be abundant in these waters.

Atlantic Mackerel

Procedures outlined by Vaughan and Saila (1976) were used to derive a survival rate for mackerel eggs to age 1 fish. This procedure utilizes the Leslie matrix algorithm to estimate early survival from proportion mature, fecundity, and survival within each age class assuming a stable population. Fecundity for Atlantic mackerel was obtained from Griswold and Silverman (1992) and Neja (1992). Age-specific instantaneous mortality was obtained from Overholtz et al. (1988) and NOAA (1995). A maximum age of 14 and maturity schedules were obtained from NFSC (1996). Since two fecundity profiles provide two egg to age 1 survival values: 2.2772E-6 for Griswold and Silverman, 2.3039E-6 for Neja, values were averaged (2.2906E-6). The observed average ratio of eggs to larvae for PNPS of 0.09143 (1980-1998) provided a larva-to-age 1 survival rate of 2.5053E-5. In calculating larvae/egg ratios 1981, 1984, and 1987 were omitted, 1981 because larvae were more abundant then eggs and 1984 and 1987 because both circulating seawater pumps were off for the mackerel egg and larval seasons during protracted maintenance outages. A mesh adjustment factor of 1.12 was applied to the egg data based on mesh comparison collections completed from 1994 through 1997 (MRI 1998). No mesh adjustment was justified for larvae. According to NOAA (1995, 1996) stock biomass consists of fish age 1 and older while fish completely recruit to the spawning stock by age 3. Therefore, adult equivalent values are shown for both age groups (Figure 11, Table 8). Age 3 individuals were estimated using an instantaneous mortality rate of M = 0.52 for age 1 fish and M = 0.37 for age 2 fish (Overholtz et al. 1988). These values provide annual survival rates of S = 0.595 and 0.691, respectively.

PNPS entrainment equivalent adult estimates for 1998 amounted to 2,633 age 1 fish or 1,082 age 3 fish. Corresponding age 1 values over the 1980 through 1997 time series ranged from 483 (1982) to 12,349 (1989) fish with an average of 4,214 (s.e. = 846). Age 3 values ranged from 199 to 5,077 with an annual average of 1,732 (s.e. = 348) individuals. Data from 1984 and 1987 were omitted here because values were unusually low as described above for the larvae/egg ratio calculations. Converting numbers of fish to weight using 0.2 and 0.7 pounds per individual (Clayton et al. 1978) resulted in an estimated average annual loss including 1998 of 824 pounds (s.e. = 174 pounds) or 1186 pounds (s.e. = 237), respectively (1984 and 1987 excluded). Weight values for 1998 alone were 527 pounds of age 1 fish, 757 pounds of age 3 fish.

According to NOAA statistical records, an annual average of 360,203 pounds (s.e. = 91,879) of mackerel were taken commercially from statistical area 514 over the years 1982-1997. For PNPS the loss of an average of 1,050 pounds of age 1 fish (1980-1997, 1984 and 1987 omitted) amounts to 0.3% of those landings and the loss of 2,368 pounds of age 3 fish, 0.7%. In addition to commercial landings, mackerel have considerable recreational value. For example, over the years 1981-1997 an average of 763,865 fish (s.e. = 138,862) were landed in Massachusetts by fishermen working inland waters and within three miles of shore. These fish had an average weight of about one pound. Unfortunately these landings are available only by state and therefore the portion attributable to Cape Cod Bay is not known. Arbitrarily adding 200,000 one-pound fish to the commercial landings brings the harvest total to 560,203 pounds and the mean PNPS EA total to 0.2 and 0.4%, respectively.

Calculations performed to estimate the number of adult cunner which would be necessary to produce the number of eggs found in the PNPS area also completed for Atlantic mackerel. Mackerel eggs occurred at Cape Cod Bay stations 2, 3, 4, 7, and 8 from early May through early July in 1975. Integration over time using the mean density of the five stations produced an estimate of 1.3529E12 eggs. This total included a mesh correction factor of 1.95 to account for extrusion through 0.505-mm mesh (MRI unpublished data). The resulting value was divided by 4, the estimated incubation time in days for mackerel eggs (Sette 1950), then divided by 319,978, an estimate of mean annual fecundity per female for age 3 fish from Griswold and Silverman (1992) and Neja (1992). Lastly the resulting value was multiplied by 2 assuming an even sex ratio. These calculations resulted in an estimated production of 3.382E11 eggs by an estimated 2,114,052 adult fish. The annual mean loss (1980-1988; 1984, 1987 omitted)of 1,694 age 3 fish due to PNPS entrainment represents 0.08% of that value.

F. Lobster Larvae Entrained

No lobster larvae were found in the 1998 entrainment samples, the total, dating back to 1974, remaining at 13. Following is a tabulation of previous collections:

1997: none found.

1996: none found.

1995: 1 larva - stage 4-5, July 28.

1994: none found.

1993: 1 larva - stage 4-5, July 21.

1991-1992: none found.

1990: 2 larvae - 1 stage 1, June 26; 1 stage 4 August 23.

1983-1989: none found.

1982: 1 larva - stage 1 on June 14.

1981: 1 larva - stage 4 on June 29.

1980: none found.

1979: 1 larva - stage 1 on July 14.

1978: none found.

1977: 3 larvae - 1 stage 1, June 10; 2 stage 1, June 17.

1976: 2 larvae - 1 stage 1, July 22; 1 stage 4-5, August 5.

1975: 1 larva - stage 1, date unknown.

1974: none found.

The lobster larvae collected in 1976 were obtained during a more intensive lobster larvae program which employed a 1-meter net, collecting relatively large sample volumes, in addition to the standard 60-cm plankton net (MRI 1977). Both larvae taken in 1976 were collected in the meter net; none were found in the routine ichthyoplankton samples.

During the three-season Cape Cod Bay neuston study for larval lobster begun in 1974, larvae were found from May through September at monthly mean densities ranging from 0.2 (September) to 3.8 per 100 m^3 (July; Matthiessen and Scherer 1983). Considering that a minimum of roughly 10,500 m^3 of water were sampled during these months each year, larval lobster must indeed be rare in the PNPS circulating water system.

SECTION V

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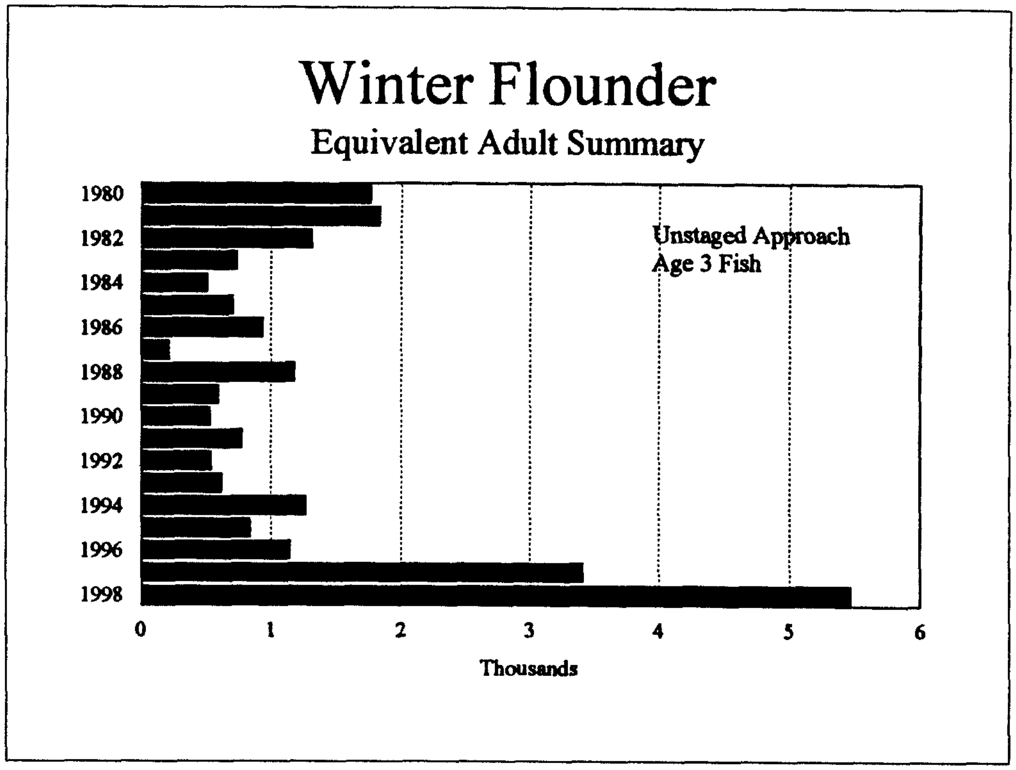

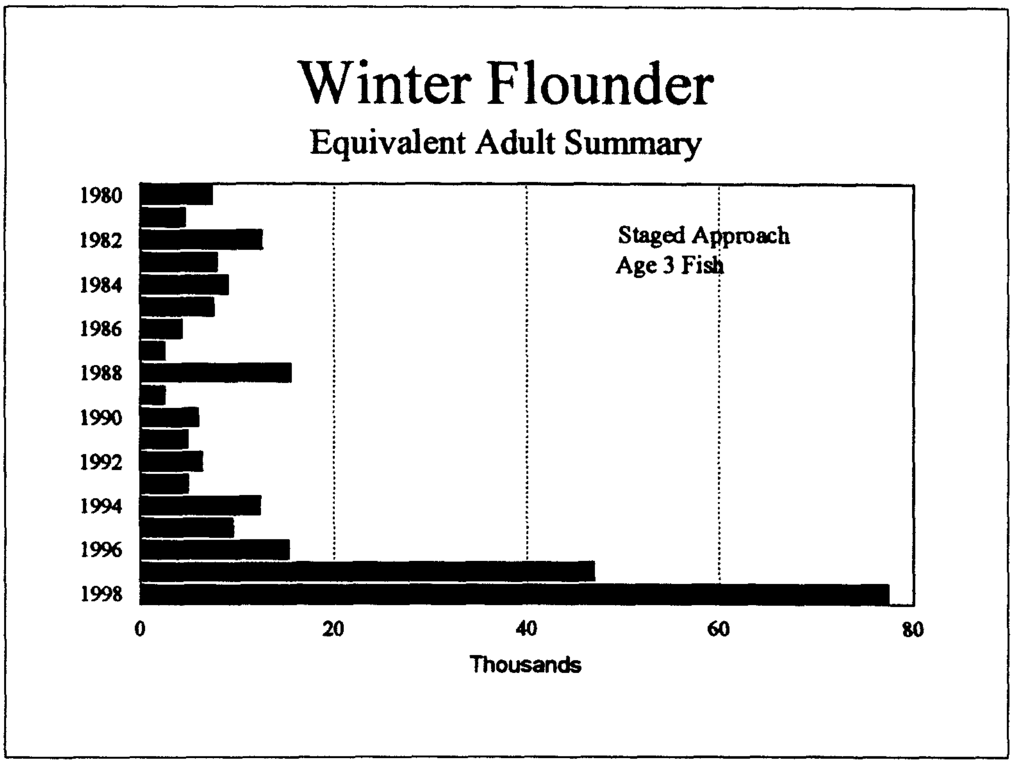

Figure 9. Numbers of equivalent adult winter flounder estimated to have been lost to entrainment at PNPS, 1980-1998.

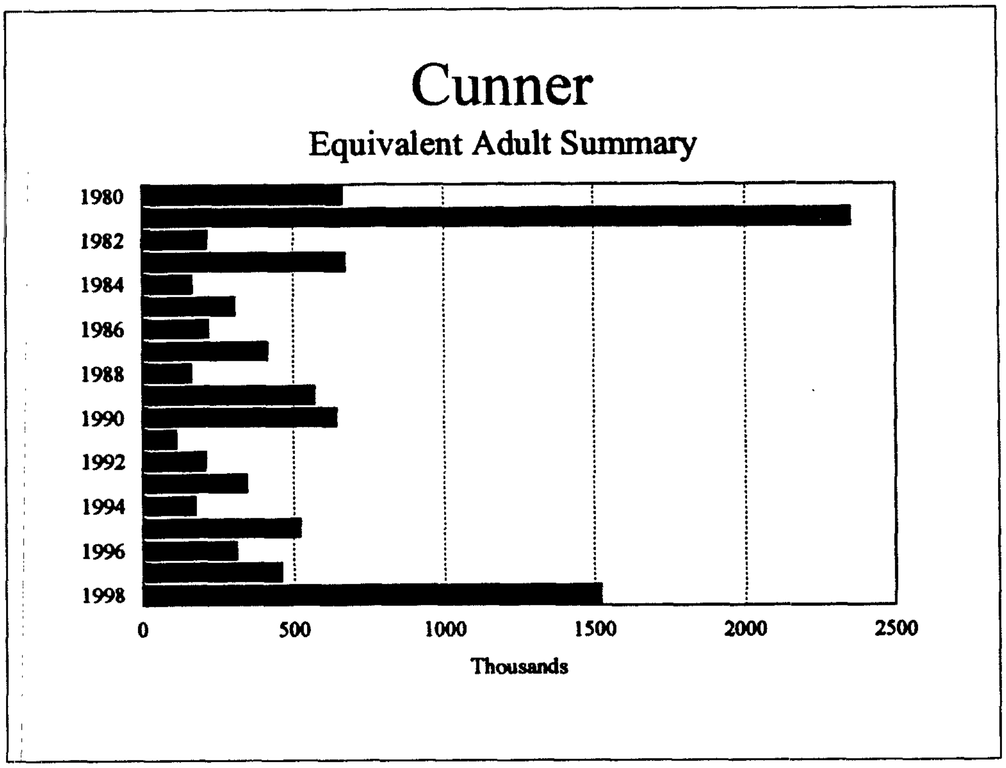

Figure 10. Numbers of equivalent adult cunner estimated to have been lost to entrainment at PNPS, 1980-1998.

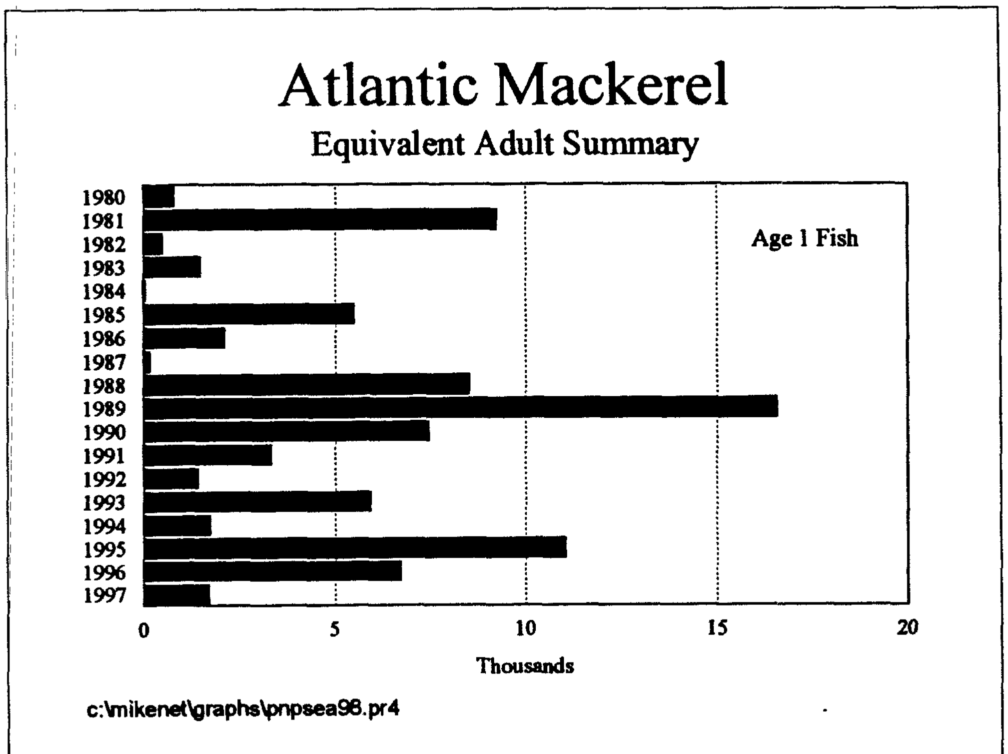

Figure 11. Numbers of equivalent adult Atlantic mackerel estimated to have been lost to entrainment at PNPS, 1980-1998.

Table 2. Species of fish eggs (E) and larvae (L) obtained in ichthyoplankton collections from the Pilgrim Nuclear Power Station discharge canal, January-December 1998.

Species		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
American eel	*Anguilla rostrata*			L									
Atlantic menhaden	*Brevoortia tyrannus*					E/L	E/L	E/L	E/L	E	E/L	E/L	
Atlantic herring	*Clupea harengus*	L		L	L	L						L	L
Bay anchovy	*Anchoa mitchilli*							E	E/L	L			
Rainbow smelt	*Osmerus mordax*					L	L	L					
Cusk	*Brosme brosme*						L	L					
Fourbeard rockling	*Enchelyopus cimbrius*		E		E/L	E/L	E/L	E/L	L	E	E	L	
Atlantic cod	*Gadus morhua*	E	E	E/L	E/L	L	E/L	L	L			E	E/L
Haddock	*Melanogrammus aeglefinus*				L	L							
Silver hake	*Merluccius bilinearis*						E/L	L	E	L	E/L	L	
Atlantic tomcod	*Microgadus tomcod*		L	L									
Hake	*Urophycis* spp.					L	E/L	E/L	E/L	E/L	E	L	
Striped cusk-eel	*Ophidion marginatum*							L	L	L			
Goosefish	*Lophius americanus*							L	L	L	E		
Silversides	*Menidia* spp.								L	L			
Northern pipefish	*Syngnathus fuscus*						L	L	L	L			
Searobins	*Prionotus* spp.						E	E	E/L	E/L			
Sea raven	*Hemitripterus americanus*			L									
Grubby	*Myoxocephalus aenaeus*	L	L	L	L	L	L						
Longhorn sculpin	*M. octodecemspinosus*		L	L	L								L
Shorthorn sculpin	*M. scorpius*		L	L	L								
Seasnail	*Liparis atlanticus*			L	L	L	L						
Black sea bass	*Centropristis striata*									L	L		
Scup	*Stenotomus chrysops*									L			

Table 2 (continued).

Species		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Wrasses	Labridae				E	E	E	E	E	E	E	E	E
Tautog	*Tautoga onitis*				L	L	L	L	L	L			
Cunner	*Tautogolabrus adspersus*					L	L	L	L	L			
Radiated shanny	*Ulvaria subbifurcata*				L	L	L	L					
Rock gunnel	*Pholis gunnellus*	L	L	L	L								L
Wrymouth	*Cryptacanthodes maculatus*			L									
Sand lance	*Ammodytes* sp.	L	L	L	L	L							L
Atlantic mackerel	*Scomber scombrus*				E	E/L	E/L	E/L	E				
Butterfish	*Peprilus triacanthus*							E/L	L	E/L			
Smallmouth flounder	*Etropus microstomus*							E	E/L	L	L		
Summer flounder	*Paralichthys dentatus*											L	
Fourspot flounder	*P. oblongus*						E/L	E/L	E/L	L			
Windowpane	*Scophthalmus aquosus*				E	E/L	E/L	E/L	E/L	E/L	E	L	
Witch flounder	*Glyptocephalus cynoglossus*				E/L		E/L	E/L	L				
American plaice	*Hippoglossoides platessoides*		E	E	E/L	L	E/L	E					
Winter flounder	*Pleuronectes americanus*			E/L	E/L	E/L	L	L					
Yellowtail flounder	*P. ferrugineus*				E	E	E/L	E/L	E/L	L			
Number of species		5	9	14	18	18	21	24	20	19	9	9	6

Table 3. Ichthyoplankton densities (number per 100 m^3 of water) for each sampling occasion during months when notably high densities were recorded, January-December 1998. Densities marked by + were unusually high based on values in Table 1. Number in parentheses indicates percent of all previous values during that month which were lower.

Atlantic mackerel larvae[1]				Winter flounder larvae			
May	1	0		May	1	1.8/1.1	
	4	0			4	52.8/32.6	
	6	0			6	10.8/6.7	
	8	0			8	7.3/4.5	
	11	STORM			11	STORM	
	13	0			13	2.7/1.7	
	15	0			15	25.6/15.8	
	18	0			18	19.8/12.2	
	20	16.8/15.0	+ (96)		20	16.1/9.9	
	22	0.9			22	49.9/30.8	
	25	88.4	+ (100)		25	6.7	
	27	377.6	+ (100)		27	573.8	+ (100)
	29	1.3			29	283.2	+ (100)
Previous high:		59	(1996)	Previous high:		148	(1974)
Notification level:		4		Notification level:		123	
June	1	16.8		June	1	58.2	+ (97)
	3	1.6			3	813.5	+ (100)
	5	112.4			5	39.1	+ (96)
	8	304.0	+ (94)		8	18.5	+ (92)
	10	49.7			10	18.8	+ (92)
	12	2.8			12	52.7	+ (97)
	15	0			15	22.8	+ (92)
	17	0			17	1.0	
	19	0.8	+ (95)		19	16.3	+ (92)
	22	362.2	+ (95)		22	0	
	24	3.2			24	14.3	+ (89)
	26	0.8			26	9.3	
	29	20.0			29	2.7	
Previous high:		2700	(1981)	Previous high:		154	(1996)
Notification level:		155		Notification level:		10	

[1]0.202 mesh densities adjusted to 0.333 mesh. Both are shown as follows: 0.202/0.333.

Table 3 (continued).

Atlantic menhaden

	EGGS		LARVAE	
June 1	11.5		0	
3	10.1		0	
5	2.0		0	
8	1.5		2.3	
10	32.9	+ (94)	0	
12	20.4	+ (88)	0	
15	1.9		0	
17	0		0	
19	0		0	
22	799.7	+ (100)	3.3	
24	11.9		17.5	+ (89)
26	5.9		4.2	
29	2.7		13.3	+ (88)
Previous high:	425	(1997)	496	(1997)
Notification level:	16		10	
July 1	6.6	+ (94)	41.1	+ (98)
3	13.7	+ (96)	1.5	
6	12.7	+ (96)	75.4	+ (99)
8	5.8	+ (93)	54.7	+ (99)
10	7.0	+ (94)	29.0	+ (96)
13	3.1		27.9	+ (96)
15	0		94.8	+ (99)
17	0		96.5	+ (99)
20	0		40.3	+ (98)
22	0		101.8	+ (99)
24	Backwash		Backwash	
27	0		5.6	+ (90)
29	0		2.7	
31	0		102.1	+ (99)
Previous high:	59	(1978)	124	(1974)
Notification level:	4		3	

Table 3 (continued).

Hake larvae

June 1	0.9	
3	0	
5	2.0	+ (95)
8	0	
10	0.7	
12	2.1	+ (95)
15	0	
17	0	
19	0	
22	18.0	+ (100)
24	0	
26	2.5	+ (97)
29	50.6	+ (100)
Previous high:	5	(1981)
Notification level:	1	

July 1	22.5	+ (99)
3	0.7	
6	62.7	+ (100)
8	18.7	+ (99)
10	7.0	+ (98)
13	176.7	+ (100)
15	28.1	+ (99)
17	0.9	
20	12.7	+ (98)
22	3.7	+ (97)
24	Backwash	
27	248.4	+ (100)
29	2.0	+ (93)
31	194.1	+ (100)
Previous high:	114	(1990)
Notification level:		1

Sept 2	48.3	+ (94)
4	1.9	
7	7.5	
9	51.1	+ (94)
11	292.4	+ (99)
14	No sample	
16	19.9	+ (86)
18	5.5	
21	1.4	
23	0	
25	2.8	
28	17.7	+ (85)
30	2.9	
Previous high:	327	(1997)
Notification level:	9	

Silver hake larvae

Sept 2	14.1	+ (98)
4	0.0	
7	0	
9	1.8	
11	6.7	+ (95)
14	No sample	
16	1.3	
18	1.8	
21	3.4	+ (92)
23	0	
25	2.2	+ (86)
28	0	
30	0	
Previous high:	32	(1975)
Notification level:	2	

Table 3 (continued).

Radiated shanny larvae

June	1	7.1	
	3	12.4	
	5	52.8	+ (99)
	8	0	
	10	0	
	12	90.0	+ (99)
	15	13.3	
	17	0	
	19	8.5	
	22	0	
	24	0.8	
	26	25.2	+ (95)
	29	0	
Previous high:		262	(1996)
Notification level:		15	

Fourbeard rockling larvae

July	1	96.8	+ (99)
	3	2.2	
	6	80.2	+ (99)
	8	108.0	+ (99)
	10	8.1	
	13	41.9	+ (98)
	15	114.1	+ (100)
	17	27.3	+ (95)
	20	66.9	+ (99)
	22	17.6	+ (91)
	24	Backwash	
	27	78.2	+ (99)
	29	19.1	+ (91)
	30	79.9	+ (99)
Previous high:		114	(1990)
Notification level:		9	

Labrid eggs

June	1	195.7	
	3	165.5	
	5	1774.7	
	8	2181.9	
	10	863.9	
	12	7173.6	
	15	551.6	
	17	228.7	
	19	36017.2	+ (100)
	22	10186.4	
	24	792.2	
	26	1184.5	
	29	1860.3	
Previous high:		37282	(1995)
Notification level:		21599	

Cunner larvae

June	1	18	
	3	0	
	5	2.0	
	8	27.0	
	10	64.5	
	12	0	
	15	0	
	17	0	
	19	3.1	
	22	2215.6	+ (100)
	24	178.2	
	26	34.5	
	29	239.9	
Previous high:		1249	(1981)
Notification level:		265	

Table 3 (continued).

Tautog larvae			**Cunnner larvae** (continued)		
July 1	5.3	+ (87)	July 1	156.4	
3	1.5		3	10.1	
6	48.4	+ (100)	6	893.6	+ (99)
8	37.5	+ (100)	8	134.0	
10	12.7	+ (97)	10	165.6	
13	89.9	+ (1000	13	796.8	+ (99)
15	268.6	+ (100)	15	1464.0	+ (99)
17	16.4	+ (98)	17	418.9	+ (98)
20	19.8	+ (98)	20	112.5	
22	17.6	+ (98)	22	113.8	
24	Backwash		24	Backwash	
27	22.3	+ (99)	27	127.0	
29	9.5	+ (94)	29	17.0	
31	25.3	+ (99)	31	140.5	
Previous high:	29	(1990)	Previous high:	2163	(1981)
Notification level:	318		Notification level:	2	
Sept 2	1.5		Sept 2	4.5	+ (91)
4	0.9		4	1.9	
7	1.3	7	7	1.3	
9	5.3	+ (95)	9	0	
11	0.8		11	4.5	+ (91)
14	No sample		14	No sample	
16	1.9		16	0.6	
18	11.0	+ (98)	18	0	
21	1.4		21	0	
23	0		23	0.9	
25	1.1		25	0	
28	5.9	+ (95)	28	0.7	
30	0		28	0	
Previous high:	19	(1996)	Previous high:	14	(1996)
Notification level:	2		Notification level:	2	

Table 4. Species of fish eggs (E) and larvae (L) collected in the PNPS discharge canal, 1975-1998. General periods of occurrence for eggs and larvae combined are shown along the right side; for the dominant species, periods of peak abundance are also shown in parentheses.

Species	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Period of Occurrence
Anguilla rostrata	J[1]	J	J		J	J								J		J				J	J	J	J	J	Feb - Jun
Alosa spp.		L	L	J	L						L					J						L			May - Jul
Brevoortia tyrannus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Jun) - (Oct)Dec
Clupeas harengus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jan - Dec[2]
Anchoa spp.	L		L	L	L		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jun - Sep
A. mitchilli			E	E	E		E	E/L			E	E			E	E	E	E	E			L		E	Jun - Sep
Osmerus mordax	L	L	L	L	L		E/L	L	L		L	L	L	L	E/L			L	L	L	L	L	L	L	Apr - Jun
Brosme brosme	E/L	E/L	E/L		E/L	E/L	E	E	E																Apr - Jul
Enchelyopus cimbrius	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Jun) - (Sep)Dec
Gadus morhua	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Jan(Nov) - (Dec)Dec
Melanogrammus aeglefinus	L	E/L	E/L	E/L	L				L		E			E		E					E	E		L	Apr - Jul
Merluccius bilinearis	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	May(May) - (Jun)Nov
Microgadus tomcod			L	L		L	L	L	L	L	L	L	L	L	L	L		L	L	L	L	L	L	L	Jan - May
Pollachius virens	E/L	E/L	E	E/L	E/L	E/L	L			L	E/L	L	E/L	L	L	L	L	E/L	L	L			E		Jan-Jun,Nov,Dec
Urophycis spp.	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(Aug) - (Sep)Nov
Ophidion marginatum	L																				L		L	L	Aug - Sep
Lophius americanus	E/L	E	E/L	E/L	E/L	L	E/L	E/L	E/L	E/L	E/L	E	E	E	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	May - Oct
Strongylura marina			L																						Jul
Fundulus spp.		E	E																						Jul
F. heteroclitus					E																				Jun
F. majalis					J													E							Oct
Menidia spp.		L	L	L	L	E/L	E/L	E	E/L	L	L	L	L	L	L	L	L	L	L	L	L	L		L	May - Sep
M. menidia	E/L	E/L	E						L								E		E						May - Sep

Table 4 (continued).

Species	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Period of Occurrence
Syngnathus fuscus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Apr - Oct
Sebastes norvegicus															L										Jun
Prionotus spp.	E/L	E		E	E	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L	E/L	E	E	E	E	E/L	E	E	E	E/L	E/L	May(Jun) - (Aug)Sep
Hemitripterus americanus																				L	L			L	Feb - Mar
Myoxocephalus spp.	L	L	L	L	L	L	L	L	E/L	L	E/L	L	L	L	E/L	L	E/L	L	L	L	L	L	L	L	Dec(Mar) - (Apr)Jul
M. aenaeus					L	L	L	L	L	L	L	L	L	L	L	L	E/L	L	L	L	L	L	L	L	Jan(Mar) - (Apr)Jul
M. octodecemspinosus						L	L	L	L	L	L	L	L	L	E/L	L	L	L	L	L	L	L	L	L	Jan(Mar) - (Apr)May
M. scorpius						L	L	L		L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Feb - Apr
Aspidophoroides monopterygius					L	L	L								L										Mar - Apr
Cyclopterus lumpus		L	L				L	L	E		L		L	L	L	E/L		E/L	L	L	L	L			Apr - Jul
Liparis spp.	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jan(Apr) - (Jun)Jul
L. atlanticus							L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Mar(Apr) - (Jun)Jul
L. coheni							L	L	L	L	L	L	L	L	L	L	L	L	L	L			L	L	Jan(Feb) - (Mar)Apr
Centropristis striata	L					L			L	L	L	L	L	L	L	L			L		L		L	L	Jul - Oct
Cynoscion regalis						L					L	L													May - Sep
Stenotomus chrysops	L		L											L	E	L	L	L	L		L		L	L	Jun - Jul(Sep)
Menticirrhus saxatilis	L				L																				Jul - Aug
Labridae	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	Mar(May) - (Aug)Sep
Tautoga onitis	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	May(Jun) - (Aug)Oct
Tautogolabrus adspersus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	May(Jun) - (Aug)Oct
Lumpenus lumpretaeformis	L						L			L	L	L		L	L	L				L		L			Jan - Jun
Ulvaria subbifurcata	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Feb(Apr) - (Jun)Oct
Pholis gunnellus	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jan(Feb) - (Apr)Jun
Cryptacanthodes maculatus				L	L		L	L	L	L	L	L			L	L	L	L	L	L	L	L	L	L	Feb - Apr

Table 4 (continued).

Species	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	Period of Occurrence
Ammodytes sp.	L	L	L	L	E/L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	Jan(Mar) - (May)Jun
Gobiosoma ginsburgi	L		L					L						L						L	L				Jul - Sep
Scomber scombrus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(May) - (Jul)Sep
Peprilus triacanthus	E/L	E/L	E/L	E	E	E/L	E/L	L	E/L	E/L	L		E	E/L	E/L	L	E/L		L	L	E/L	L	L	E/L	May - Oct
Etropus microstomus	L								L		E	E/L	E		E		E	E	E		E/L	E/L	E/L	E/L	Jul - Oct
Paralichthys dentatus	E/L								E/L		L		E/L	E		L			E/L	E	E/L	L		L	Sep - Nov
P. oblongus[1]		E/L	E/L		E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E\L	E\L	E/L	E/L	E/L	E/L	E/L	May - Oct
Scophthalmus aquosus[3]	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Apr(May) - (Sep)Oct
Glyptocephalus cynoglossus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	-E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Mar(May) - (Jun)Nov
Hippoglossoides platessoides	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Jan(Mar) - (Jun)Nov
Pleuronectes americanus	E/L	E/L	L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Jan(Apr) - (Jun)Aug
P. ferrugineus	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	E/L	Feb(Apr) - (May)Nov
P. putnami							L	E/L													L				Mar - Jun
Trinectes maculatus			E	E			E	E				E		E	E/L	E/L	E								May - Sep
Sphoeroides maculatus			L								L														Jul - Aug
Number of Species[4]	41	36	43	35	37	35	40	38	37	34	42	37	36	41	40	42	34	36	38	40	42	38	37	40	

[1]J = juvenile.

[2]Absent August and September; peaks = March-May and November-December.

[3]Although these eggs were not identified specifically, they were assumed to have occurred as shown based on the occurrence of larvae.

[4]For comparative purposes three species of Myoxocephalus were assumed for 1975-1978 and two species of Liparis for 1975-1980.

Table 5. Numbers of larval winter flounder entrained at PNPS annually by stage, 1980 - 1998. Number and weight of equivalent age 3 adults calculated by two methods is also shown.

	Number Of Larvae Entrained Stage				Equivalent Age 3 Adults			
Year	1[1]	2[1]	3	4	General		Staged	
					Number	Pounds	Number	Pounds
1980	8,694,456	12,714,822	7,317,129	0	1,771	1,063	7,443	4,466
1981	7,606,942	19,133,121	3,073,126	43,304	1,841	1,105	4,689	2,813
1982	2,706,834	6,724,795	11,583,134	425,011	1,322	793	12,643	7,586
1983	1,933,453	2,246,172	7,558,534	260,350	740	444	7,969	4,781
1984	248,082	0	7,570,145	516,247	514	308	9,128	5,477
1985	1,039,001	2,312,789	8,025,452	130,786	710	426	7,643	4,586
1986	5,397,403	5,783,669	3,963,747	77,005	939	563	4,365	2,619
1987	0	437,608	3,088,405	0	217	130	2,619	1,571
1988	1,995,968	1,656,376	15,079,960	511,009	1,187	712	15,558	9,335
1989	1,668,823	5,755,240	2,224,675	39,114	597	358	2,624	1,574
1990	643,683	1,155,404	6,846,718	33,002	535	321	6,016	3,610
1991	3,471,022	3,908,488	5,188,056	37,717	777	466	4,966	2,980
1992	873,660	876,914	7,034,690	26,192	543	326	6,114	3,668
1993	1,595,700	3,540,750	4,934,952	88,617	626	376	4,958	2,975
1994	1,034,617	6,433,716	13,060,373	172,606	1,276	766	12,446	7,468
1995	1,632,907	2,820,023	8,826,496	375,857	842	505	9,699	5,819
1996	504,810	5,818,499	11,329,855	995,127	1,150	690	15,395	9,237
1997	2,225,634	9,537,788	41,484,016	2,126,280	3,414	2,048	47,087	28,252
Mean	2,404,055	5,047,565	9,343,859	325,457	1,056	633	10,076	6,045
s.e.	578,064	1,140,968	2,067,069	122,466	173	104	2,368	1,421
1984, 1987 Omitted[2]								
Mean	2,689,057	5,651,160	9,845,682	333,874	1,142	685	10,601	6,361
s.e.	614,157	1,200,337	2,292,345	136,105	183	110	2,626	1,576
1998	5,099,963	20,202,973	58,546,916	4,904,482	5,473	3,284	77,428	46,457

[1] Mesh factor = 1.62 applied to Stages 1 and 2 prior to 1995.

[2] See text for details.

Table 6. Area 514 commercial landings and Massachusetts recreational landings from inland waters for winter flounder (pounds), 1982 - 1997.

	Commercial (pounds)	Recreational (pounds)	Total (pounds)
1982	3,830,162	4,146,553	7,976,715
1983	2,936,176	874,245	3,810,421
1984	2,558,483	839,561	3,398,044
1985	2,450,319	1,858,645	4,308,964
1986	1,667,938	708,677	2,376,615
1987	1,739,664	568,822	2,308,486
1988	1,846,171	729,200	2,575,371
1989	1,896,609	1,163,315	3,059,924
1990	1,737,733	139,641	1,877,374
1991	1,520,470	67,659	1,588,129
1992	1,326,646	85,256	1,411,902
1993	1,057,211	147,287	1,204,498
1994	328,706	71,403	400,109
1995	16,788	43,362	60,150
1996	2,961	69,871	72,832
1997	1,798	69,893	71,691

ble 7. Numbers of cunner eggs and larvae entrained at PNPS annually, 1980 - 1998.
Numbers of equivalent adults are also shown.

Cunner	Eggs	Larvae Stage 1	Stage 2	Stage 3	Total	Equivalent Adults
1980	3,257,891,776	76,282,260	40,480,032	4,229,248	120,991,540	667,485
1981	6,576,294,915	316,245,739	256,567,950	3,508,876	576,322,566	2,353,607
1982	2,010,779,150	6,351,445	3,187,760	597,356	10,136,561	216,418
1983	5,895,329,347	10,961,646	27,571,530	3,955,802	42,488,978	673,201
1984	1,766,764,864	0	176,682	1,029,352	1,206,034	166,823
1985	2,021,886,071	17,182,039	20,392,615	2,307,617	39,882,271	307,573
1986	1,493,653,289	4,419,092	22,197,318	297,368	26,913,778	219,494
1987	4,465,564,080	40,247,222	314,474	248,738	40,810,434	415,062
1988	1,539,089,318	2,290,972	2,624,077	2,461,452	7,376,502	164,492
1989	4,469,416,004	34,100,052	15,224,141	2,863,938	52,188,130	570,900
1990	1,336,048,112	65,705,970	62,378,298	44,014,528	172,098,797	644,849
1991	675,000,390	5,790,172	3,701,490	7,243,966	16,735,627	113,048
1992	2,174,661,078	0	1,186,819	1,605,055	2,791,875	209,299
1993	3,235,317,207	148,674	7,178,133	7,923,303	15,250,109	345,004
1994	1,558,253,667	0	5,545,977	4,440,095	9,986,072	174,169
1995	4,116,491,874	7,961,638	29,910,748	9,257,792	47,130,178	522,981
1996	2,807,124,109	3,765,455	8,094,509	5,558,849	17,418,813	312,029
1997	1,718,289,720	6,444,923	51,895,511	41,294,559	99,634,994	460,586
›an	2,839,880,832	33,216,517	31,034,892	7,935,439	72,186,848	474,279
l. Dev.	1,660,270,370	74,242,592	59,254,322	12,902,781	133,801,355	505,078
ınt	18	18	18	18	18	18
.	391,329,479	17,499,147	13,966,378	3,041,215	31,537,282	119,048
›dian	2,098,273,575	6,398,184	11,659,325	3,732,339	33,398,025	328,516
›omean	2,421,129,559		8,911,803	3,252,772	27,076,301	352,116
ithout 1981						
›an	2,620,091,768	16,567,739	17,768,242	8,195,825	42,531,805	363,730
l. Dev.	1,415,945,969	23,566,038	19,090,312	13,251,044	46,933,901	193,187
ınt	17	17	17	17	17	17
.	343,417,341	5,715,604	4,630,081	3,213,850	11,383,143	46,855
›dian	2,021,886,071	6,351,445	8,094,509	3,955,802	26,913,778	312,029
›omean	2,282,920,458		7,313,548	3,238,303	22,618,677	314,886
1998	4,341,664,826	104,908,332	211,248,501	54,060,618	370,217,451	1,522,731

Table 8 . Numbers of Atlantic mackerel eggs and larvae entrained at PNPS annually, 1980 - 1998. Numbers of equivalent age 1 and age 3 fish are also shown.

Year	Total Number Entrained Eggs	Total Number Entrained Larvae	Equivalent Adults Age 1	Equivalent Adults Age 3
1980	81,599,432	22,293,108	745	306
1981	183,959,791	320,135,596	8,442	3,471
1982	108,234,931	9,388,143	483	199
1983	148,616,621	41,333,673	1,376	566
1984	22,486,619	78,315	53	22
1985	1,867,648,438	45,711,343	5,423	2,230
1986	219,488,066	58,333,520	1,964	808
1987	71,222,294	215,561	169	69
1988	2,663,608,568	3,401,489	6,186	2,544
1989	4,673,915,938	65,562,469	12,349	5,077
1990	2,313,416,455	4,627,282	5,415	2,226
1991	479,761,865	66,009,482	2,753	1,132
1992	377,610,764	8,086,393	1,068	439
1993	1,801,378,418	8,325,789	4,335	1,782
1994	520,917,221	3,419,299	1,279	526
1995	1,767,609,278	197,689,693	9,002	3,701
1996	1,507,370,682	70,947,053	5,230	2,150
1997	316,969,390	25,778,062	1,372	564
Mean	1,062,545,265	52,852,015	3,758	1,545
s.e.	296,892,824	19,268,231	833	343
Mean w/o 1984,1987	1,189,506,616	59,440,150	4,214	1,732
s.e.	310,913,433	20,518,466	846	348
1998	530,017,006	56,622,648	2,633	1,082

APPENDIX A*. Densities of fish eggs and larvae per 100 m³ of water recorded in the PNPS discharge canal by species, date, and replicate, January-December 1998.

*Available upon request.

APPENDIX B*. Geometric mean monthly densities and 95% confidence limits per 100 m^3 of water for the dominant species of fish eggs and larvae entrained at PNPS, January-December 1981-1998.

Note the following:

When extra sampling series were required under the contingency sampling regime, results were included in calculating monthly mean densities.

Shaded columns for certain months in 1984 and 1987 delineate periods when sampling was conducted with only salt service water pumps in operation. Densities recorded at those times were probably biased low due to low through-plant water flow (MRI 1994).

*Available upon request.

IMPINGEMENT OF ORGANISMS AT

PILGRIM NUCLEAR POWER STATION

(January - December 1998)

Prepared by: Robert D. Anderson

Robert D. Anderson

Principal Marine Biologist

Regulatory Affairs Department

Boston Edison Company

April 1999

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SECTION I

SUMMARY

Fish impingement rate averaged 1.30 fish/hour during the period January-December 1998, which is considerably lower than most recent years partially because of no large impingement incidents. Atlantic silverside (Menidia menidia) accounted for 51.6% of the fishes collected followed by winter flounder (Pleuronectes Americanus) at 13.1%. Atlantic menhaden (Brevoortia tyrannus) and rainbow smelt (Osmerus mordax) represented 8.7 and 6.8%, respectively, of the fishes impinged. The peak period was March/April when fish impingement was dominated by Atlantic silversides. This time period is typical for high silverside impingement. Initial impingement survival for all fishes from static screen wash collections was approximately 32% and from continuous screen washes 51%.

At 100% yearly (January-December) operation of Pilgrim Nuclear Power Station (PNPS) the estimated annual impingement was 11,426 fishes. The PNPS capacity factor was 97.1% during 1998.

The collection rate (no./hr.) for all invertebrates captured from January-December 1998 was 1.11+. Blue mussel (Mytilus edulis) and sevenspine bay shrimp (Crangon septemspinosa) were most numerous. Longfin squid (Loligo pealei) and Green crab (Carcinus maenus) accounted for 10.0 and 5.3%, respectively, of the invertebrates impinged and enumerated. Mixed species of algae collected on intake screens amounted to 1,980 pounds.

SECTION 2

INTRODUCTION

Pilgrim Nuclear Power Station (lat. 41°56' N, long. 70°34' W) is located on the northwestern shore of Cape Cod Bay (Figure 1) with a licensed capacity of 670 MWe. The unit has two circulating water pumps with a capacity of approximately 345 cfs each and five service water pumps with a combined capacity of 23 cfs. Water is drawn under a skimmer wall, through vertical bar racks spaced approximately 3 inches on center, and finally through vertical traveling water screens of 3/8 inch wire mesh (Figure 2). There are two traveling water screens for each circulating water pump.

This document is a report pursuant to operational environmental monitoring and reporting requirements of NPDES Permit No. 0003557 (USEPA) and No. 359 (Mass. DEP) for Pilgrim Nuclear Power Station, Unit I. The report describes impingement of organisms and survival of fishes carried onto the vertical traveling water screens at Unit I. It presents analysis of the relationships among impingement, environmental factors, and plant operational variables.

This report is based on data collected from screen wash samples during January-December 1998.

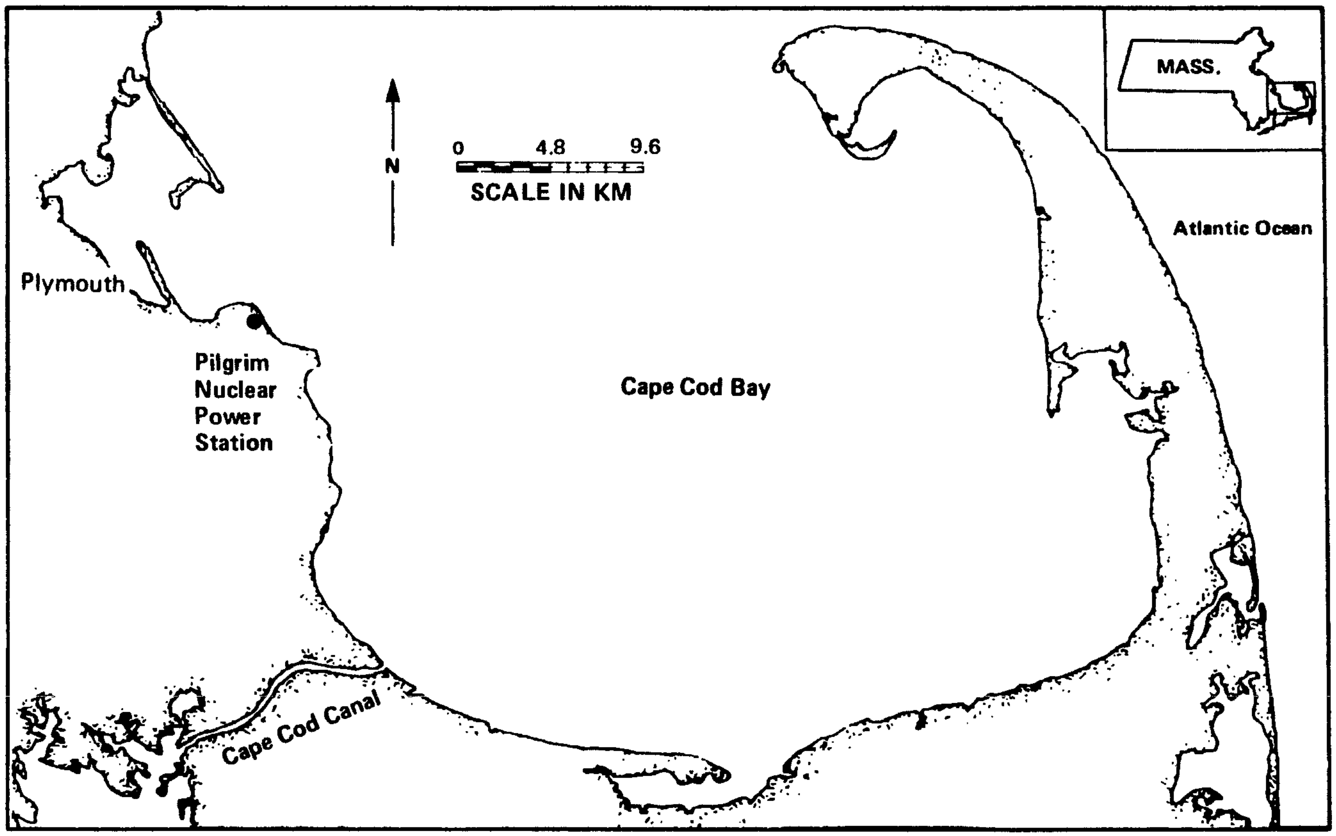

Figure 1. Location of Pilgrim Nuclear Power Station.

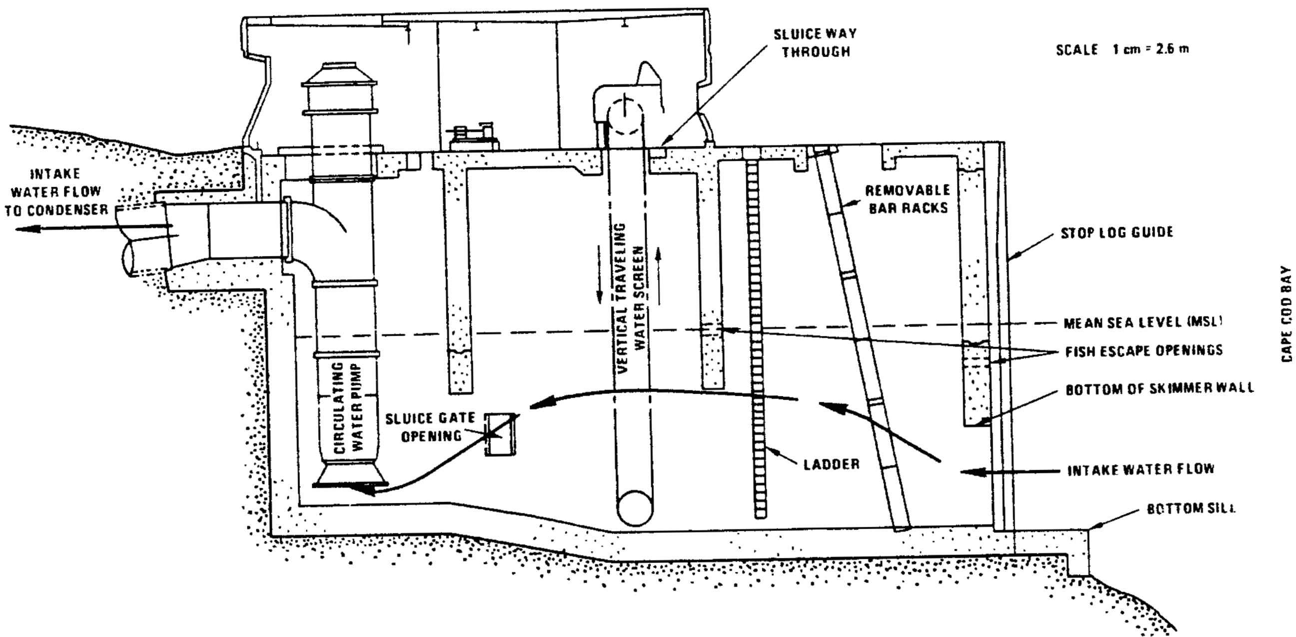

Figure 2: Cross-section of intake structure of Pilgrim Nuclear Power Station.

SECTION 3

METHODS AND MATERIALS

Three screen washings each week were performed from January-December 1998 to provide data for evaluating the magnitude of marine biota impingement. The total weekly collection time was 24 hours (three separate 8-hour periods: morning, afternoon and night). Two collections represented dark period sampling and one represented light period sampling. At the beginning of each collection period, all four traveling screens were washed. Eight hours later, the screens were again washed (minimum of 30 minutes each) and all organisms collected. When screens were being washed continuously, one hour collections were made at the end of the regular sampling periods, and they represented two light periods and one dark period on a weekly basis.

Water nozzles directed at the screens washed impinged organisms and debris into a sluiceway that flowed into a trap. The trap was made of galvanized screen (3/8-inch mesh) attached to a removable steel frame and it collected impinged biota, in the screenhouse, shortly after being washed off the screens. Initial fish survival was determined for static (8-hour) and continuous screenwash cycles.

Variables recorded for organisms were total numbers, and individual total lengths (mm) and weights (gms) for up to 20 specimens of each species. A random sample of 20 fish or invertebrates was taken whenever the total number for a species exceeded 20; if the total collection for a species was less than 20, all were measured and weighed. Field work was conducted by Marine Research, Inc. Intake seawater temperature, power level output, tidal stage, number of circulating water pumps in operation, time of day and date were recorded at the time of collections. The collection rate (#/hour) was calculated as number of organisms impinged per collecting period divided by the total number of hours in that collecting period.

Beginning in 1990, if all four intake screens are not washed for a collecting period then the number of fishes collected is increased by a proportional factor to account for the unwashed screens, as requested by the Pilgrim Administrative-Technical Committee. Common and scientific names in this report follow the American Fisheries Society (1988, 1989, 1991a and 1991b) or other accepted authority when appropriate.

SECTION 4

RESULTS AND DISCUSSION

4.1 Fishes

In 575 collection hours, 750 fishes of 36 species (Table 1) were collected from Pilgrim Nuclear Power Station intake screens during January - December 1998. The collection rate was 1.30 fish/hour. This annual impingement rate was relatively low compared to most recent years primarily because of previous, large impingement incidents of Atlantic silverside (Menidia menidia) and/or rainbow smelt (Osmerus mordax) and alewife (Alosa pseudoharengus). Atlantic silverside was the most abundant species in 1998 accounting for 51.6%% of all fishes collected, followed by winter flounder (Pleuronectes americanus) at 13.1% (Table 2). Atlantic menhaden (Brevoortia tyrannus) and rainbow smelt accounted for 8.7 and 6.8% of the total number of fishes collected and identified to lowest taxon.

Atlantic silverside occurred most predominately in monthly samples from March and April. Hourly collection rates per month for them ranged from 0 to 4.53. Silverside impinged in March and April accounted for 89% of all this species captured in impingement collections from January-December 1998. They averaged 98 mm total length and 4 grams in weight. Their impingement indicated no relationship to tidal stage or diel factors. They are usually the dominant fish in the annual impingement catch, being the most abundant species caught in seven of the last ten years. Impingement histories of abundant species impinged at Pilgrim Station in 1998, over the past 10 years, are documented in Table 3.

Winter flounder were relatively prevalent in April and December samples, indicative of this species' juvenile stage movements. It has been one of the more commonly impinged fish over the years.

Intake Screens, January - December

Species	Jan.	Feb.	March	April	May	June	July	August	Sep.	Oct.	Nov.	Dec.	Total
Atlantic silverside	33	7	145	200	1							1	387
Winter flounder	8	16	10	34	1	1					1	27	98
Atlantic menhaden								30	32	2		1	65
Rainbow smelt	9	29		2				3	2	1		5	51
Windowpane	3	3	1	15	2	1							25
Lumpfish			1		15							3	19
Grubby	4		4	5	1							3	17
Alewife				9			2	1			1		13
Blueback herring			3	4								1	8
Atlantic herring			1	2	2				1	1			7
Hake spp					2	4							6
Atlantic cod				2	3								5
Cunner	1				1						1	2	5
Little skate						2	3						5
Red hake					1		1				2		4
Threespine stickleback	2		1	1									4
Radiated shanny	1		1	1									3
Tautog	2			1							1	2	5
Atlantic tomcod											1	1	2
Butterfish									1	1			2
Rock gunnel				1	1								2
Sand lance sp.											2		2
Spotted hake				2									2
Striped killifish									1		1		2
White perch												2	2
Atlantic moonfish										1			1
Bluefish										1			1
Fourbeard rockling				1									1
Fourspot flounder						1							1
Longhorn sculpin												1	1
Northern searobin						1							1
Scup						1							1
Silver hake												1	1
Smallmouth flounder				1									1
Striped cusk-eel								1					1
Summer founder					1								1
Totals	63	55	167	281	31	11	6	35	37	7	9	48	750
Collection Time (hrs.)	26	17	32	67	71	114	64	39	29	43	38	35	575
Collection Rate (#hr.)	2.42	3.24	5.22	4.19	0.44	0.10	0.09	0.90	1.28	0.16	0.24	1.37	1.30

Table 2. Species, Number, Total Length (mm), Weight (gms) and Percentage For All Fishes Collected From Pilgrim Station Impingement Sampling, January -December 1998

Speicies	Number	Length Range	Mean Range	Weight Range	Mean Weight	Percent Of Total Fish
Atlantic silverside	387	70-135	98	2-9	4	51.6
Winter flounder	98	39-277	77	-	-	13.1
Atlantic menhaden	65	46-90	66	1-7	3	8.7
Rainbow smelt	51	70-157	107	1-21	7	6.8
Windowpane	25	47-291	87	-	-	3.3
Lumpfish	19	31-80	43	1-12	3	2.5
Grubby	17	50-90	62	2-7	3	2.3
Alewife	13	68-118	89	2-12	5	1.7
Blueback herring	8	66-96	82	2-5	4	1.1
Atlantic herring	7	42-275	98	0.2-170	27	0.9
Hake spp.	6	60-117	73	1-10	3	0.8
Atlantic cod	5	53-67	57	1-3	2	0.7
Cunner	5	46-108	83	1-16	11	0.7
Little skate	5	357-485	423	-	-	0.7
Red hake	4	68-137	93	2-13	5	0.5
Threespine stickleback	4	36-62	50	1-5	2	0.5
Radiated shanny	3	78-130	97	4-18	9	0.4
Tautog	3	75-132	96	5-41	18	0.4
Atlantic tomcod	2	120-130	125	12-19	16	0.3
Butterfish	2	40-53	47	1-2	2	0.3
Rock gunnel	2	67-148	108	1-9	5	0.3
Sand lance sp.	2	122-156	139	6-11	8	0.3
Spotted hake	2	76	76	3	3	0.3
Striped killifish	2	75-85	80	6-7	7	0.3
White perch	2	92-100	96	9-12	10	0.3
Atlantic moonfish	1	50	50	2	2	0.1
Bluefish	1	685	685	-	-	0.1
Fourbeard rockling	1	74	74	2	2	0.1
Fourspot flounder	1	163	163	-	-	0.1
Longhorn sculpin	1	328	328	-	-	0.1
Northern searobin	1	170	170	37	37	0.1
Scup	1	190	190	94	94	0.1
Silver hake	1	71	71	2	2	0.1
Smallmouth flounder	1	52	52	1	1	0.1
Striped cusk-eel	1	192	192	29	29	0.1
Summer flounder	1	365	365	-	-	0.1

Table 3. Annual Impingement collections (1989 - 1998) for the 10 Most Abundant Fishes From Pilgrim Station Intake Screens During January - December 1998

Species	1989	1990	1991	1992	1993	1994*	1995**	1996	1997	1998	Totals
	Number of Impinged fishes Collected From January - December										
Atlantic silverside	120	457	275	232	720	3,112	1,100	765	302	387	7,470
Winter flounder	42	31	67	72	90	90	92	41	40	98	663
Atlantic menhaden	82	345	113	2	4	14	73	75	56	65	829
Rainbow smelt	39	38	41	25	735	896	162	174	82	51	2,243
Windowpane	6	15	11	3	10	14	10	13	4	25	111
Lumpfish	3	8	5	10	36	17	9	8	9	19	124
Grubby	29	59	46	43	51	98	45	57	23	17	468
Alewife	8	131	24	22	52	11	1,871	11	15	13	2,158
Blueback herring	15	103	31	11	25	24	87	58	18	8	380
Atlantic herring	16	35	2,370	3	10	3	10	0	1	7	2,455
Totals	360	1,222	2,983	423	1,733	4,279	3,459	1,202	550	690	16,901
Collection Time (hrs.)	618	919.50	930.25+	774	673.50	737.39	607.67	416	455	575	6,706.91+
Collection Rate (#/hr.)	0.58	1.33	3.21	0.55	2.57	5.80	5.69	2.89	1.21	1.20	2.52

* No CWS pumps were in operation 9 October - 16 November 1994.
**No CWS pumps were in operation 30 March - 15 May 1995.

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Atlantic menhaden were prevalent in August/September samples and have been most abumdant in the early fall period, ranking third in 1986/1991/1997 and second in 1989/1990. Generally, it has been one of the less impinged fish over the years.

Rainbow smelt were abundant in February impingement collections and have been most prevalent in the late Fall/ Winter period in the past, ranking first in 1978, 1987 and 1993 in total numbers impinged. In 1978, 1993 and 1994, large impingement incidents involving smelt occurred during December. Monthly intake water temperatures and impingement rates for the five dominant species in 1998 are illustrated in Figure 3.

There were no small fish impingement incidents (20 fish or greater/hr.) at Pilgrim Station in 1998. There were no large fish impingement incidents (1,000 fish or greater) in 1998 on intake screens. Most large fish impingement mortalities have occurred while both circulating water pumps were operating.

Fifteen large fish incidents have been documented since Pilgrim operation in 1973, and most (11) have involved impingement as the causative agent (Table 4). However, at least in two of these, the possibility of pathological influence was implicated as indirectly contributing to the mortalities. They were the Atlantic herring (tubular necrosis) and rainbow smelt (piscine erythrocytic necrosis) impingement incidents in 1976 and 1978, respectively.

Fish impingement rate at Pilgrim Station has been shown to be related to the number of circulating water pumps operating, in general (Lawton, Anderson et al,1984b). Reduced pump operation has lowered total impingement, particularly during the April to mid-August 1984 and portions of the mid-February to August 1987 periods when no circulating water pumps were operating for extended time frames. *The significance of this relationship is supported by the*

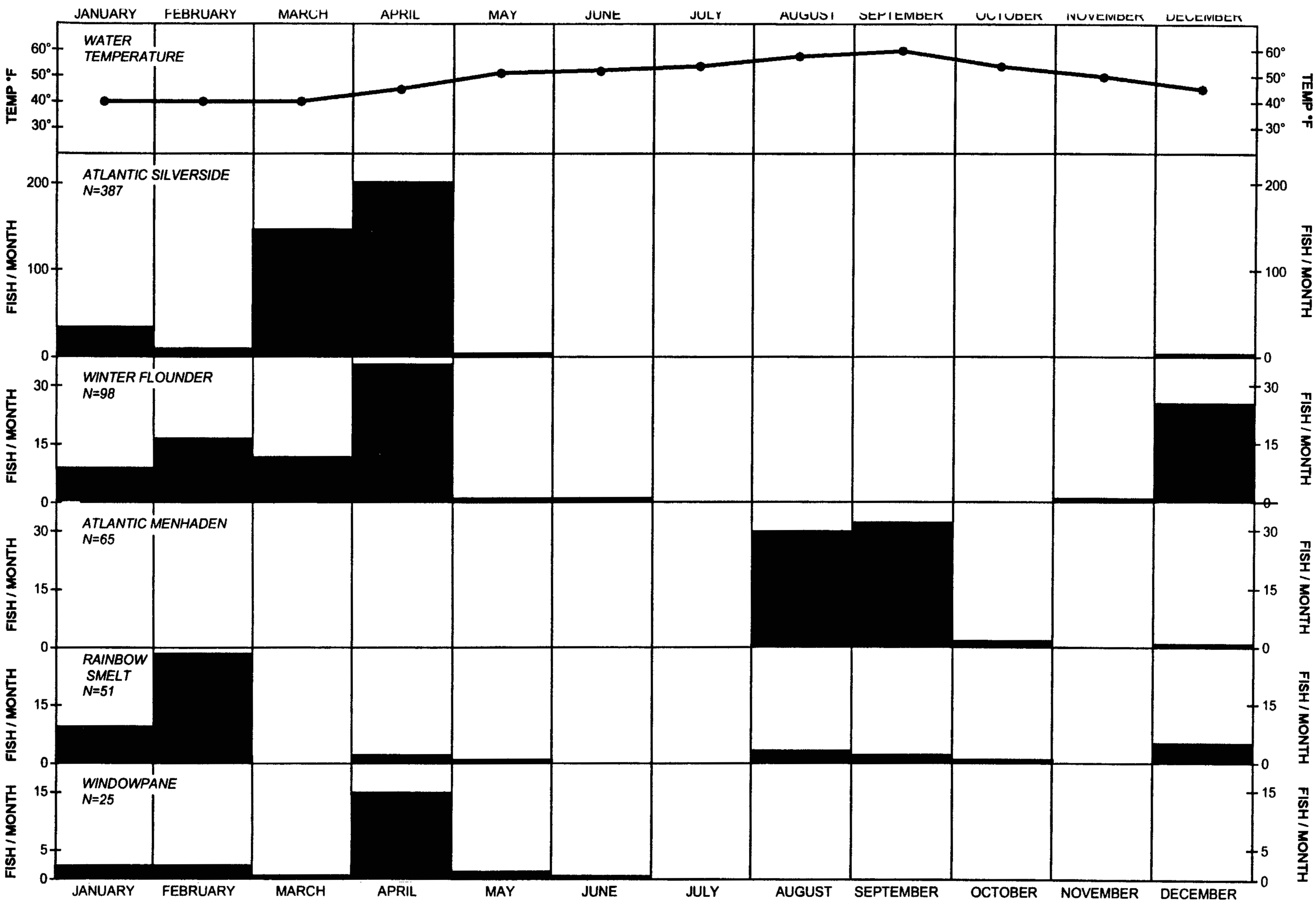

Figure 3. Trends of Intake Water Temperature, and Number of Fish Captured by Month from Pilgrim Station Intake Screens for the Five Most Abundant Species Collected, January - December 1998.

fish_mo

Table 4. Approximate Number and Cause for Dominant Species of Most Notable Fish Mortalities Pilgrim Nuclear Power Station, 1973-1998

Date	Species	Number	Cause
April 9-19, 1973	Atlantic menhaden	43,000	Gas Bubble Disease
August/September, 1973	Clupeids	1,600	Impingement
April 2-15, 1975	Atlantic menhaden	5,000	Gas Bubble Disease
August 2, 1975	Atlantic menhaden	3,000	Thermal Stress
August 5, 1976	Alewife	1,900	Impingement
November 23-28, 1976	Atlantic herring	10,200	Impingement
August 21-25, 1978	Clupeids	2,300	Thermal Stress
December 11-29, 1978	Rainbow smelt	6,200	Impingement
March/April, 1979	Atlantic silverside	1,100	Impingement
September 23-24, 1981	Atlantic silverside	6,000	Impingement
July 22-25, 1991	Atlantic herring	4.200	Impingement
December 15-28, 1993	Rainbow smelt	5,100	Impingement
November 28-29, 1994	Atlantic silverside	5,800	Impingement
December 26-28, 1994	Atlantic silverside	6,100	Impingement
	Rainbow smelt	5,300	Impingement
September 8-9, 1995	Alewife	13,100	Impingement

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fact that total fish impingement and rate of fish impingement were several times lower in 1984 and 1988 (low-pump operation years) than in 1989 - 1998, despite a greater number of collecting hours in 1984 and an average number of hours in 1988. In 1987, far fewer collecting hours were possible when both circulating pumps were off than in these other years which limits comparisons to them. However, total fish impingement rates in 1984, 1987 and 1988 were several times lower than in 1989-1998 when at least one circulating pump was more consistently in operation. Although there were brief periods in 1994 and 1995 when no circulating water pumps were operational, mixed results were noted regarding the effect on impingement of pump operation, possibly influenced by conditions causing large impingement incidents each of these years.

Projected fish impingement rates were calculated assuming 100% operation of Pilgrim Nuclear Power Station, under conditions at the times of impingement, during the period January-December 1998. Table 5 presents hourly, daily, and yearly impingement rates for each species captured (rates are rounded to significant figures). For all fishes combined, the respective rates were 1.30, 31.30 and 11,426. The yearly rate of 11,426 is below normal and only 57% of the last 20-years' (1979-1998) mean annual projection of 19,911 fishes (Table 6). This was considerably lower than most recent years' rates which were the highest yearly fish impingement rates since 1981 and which greatly exceeded the historical annual average partially because several large impingement incidents inflated yearly projections. Relatively high impingement rate years offset low impingement years, and they may be attributed to population variances of the dominant species and/or extreme meteorological or operational conditions influencing species' behavior and vulnerability.

Over the past 20-year period (1979-1998), Pilgrim Station has had a mean impingement rate of 2.27 fishes/hr., ranging from 0.13 (1984) to 10.02 (1981) (Table 6). Anderson et al. (1975) documented higher annual impingements at seven other northeast power plants in the early

Table 5. Impingement Rates Per Hour, Day and Year For All Fishes Collected From Pilgrim Statio Intake Screens During January - December 1998. Assuming 100% Operation of Pilgrim Unit 1*

Species	Rate/Hr.	Rate/Day	Rate/January-December 1998	Dominant Months Of Occurrence
Atlantic silverside	0.67	16.15	5,896	April
Winter flounder	0.17	4.09	1,493	April
Atlantic menhaden	0.11	2.71	990	August/September
Rainbow smelt	0.09	2.13	777	February
Windowpane	0.04	1.04	381	April
Lumpfish	0.03	0.79	289	May
Grubby	0.03	0.71	259	April
Alewife	0.02	0.54	198	April
Blueback herring	0.01	0.33	122	April
Atlantic herring	0.01	0.29	107	April/May
Hake spp.	0.01	0.25	91	June
Atlantic cod	0.01	0.21	76	May
Cunner	0.01	0.21	76	December
Little skate	0.01	0.21	76	July
Red hake	0.01	0.17	61	November
Threespine stickleback	0.01	0.17	61	January
Radiated shanny	0.01	0.13	46	March/April
Tautog	0.01	0.13	46	January
Atlantic tomcod	0.003	0.08	30	November/December
Butterfish	0.003	0.08	30	April/May
Rock gunnel	0.003	0.08	30	April/May
Sand lance sp.	0.003	0.08	30	November
Spotted hake	0.003	0.08	30	April
Striped killifish	0.003	0.08	30	September/November
White perch	0.003	0.08	30	December
Atlantic moonfish	0.002	0.04	15	October
Bluefish	0.002	0.04	15	October
Fourbeard rockling	0.002	0.04	15	April
Fourspot flounder	0.002	0.04	15	June
Longhorn sculpin	0.002	0.04	15	December
Northern searobin	0.002	0.04	15	June
Scup	0.002	0.04	15	June
Silver hake	0.002	0.04	15	December
Smallmouth flounder	0.002	0.04	15	April
Striped cusk-eel	0.002	0.04	15	August
Summer flounder	0.002	0.04	15	May
Totals	1.30	31.30	11,426	

*Rates have been rounded to significant figures.

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Table 6. Impingement Rates Per Hour, Day and Year For All Fishes Collected From Pilgrim Station Intake Screens During 1979-1998, Assuming 100% Operation of Pilgrim Unit 1*

Year	Rate/Hr.	Rate/Day	Rate/Year	Dominant Specie (Rate/Year)
1979	3.24	77.69	28,280	Atlantic silverside (20,733)
1980	0.66	15.78	5,769	Cunner (1,683)
1981	10.02	240.42	87,752	Atlantic silverside (83,346)
1982	0.93	22.39	8,173	Atlantic silverside (1,696)
1983	0.57	13.65	4,983	Atlantic silverside (1,114)
1984+	0.13	3.13	1,143	Atlantic silverside (185)
1985	1.14	27.46	10,022	Atlantic silverside (3,278)
1986	1.26	30.34	11,075	Atlantic herring (3,760)
1987+	0.28	6.74	2,460	Rainbow smelt (682)
1988+	0.27	6.48	2,372	Atlantic silverside (586)
1989	0.80	19.30	7,045	Atlantic silverside (1,701)
1990	1.70	40.74	14,872	Atlantic silverside (4,354)
1991	3.38	81.14	29,616	Atlantic Herring (22,318)
1992	0.63	15.22	5,572	Atlantic silverside (2,633)
1993	2.78	66.78	24,375	Rainbow Smelt (9,560)
1994+	5.97	143.18	52,259	Atlantic silverside (36,970)
1995+	5.87	141.00	51,464	Alewife (26,972)
1996	3.11	74.64	27,318	Atlantic silverside (16,153)
1997	1.43	34.29	12,514	Atlantic silverside (5,814)
1998	1.30	31.30	11,426	Atlantic silverside (5,896)
Means	2.27	54.55	19,911	

*Rates have been rounded to significant figures.
+No CWS pumps were in operation 29 March - 13 August 1984, 18 February - 8 September 1987, 14 April - 5 June 1988, 9 October - 16 November 1994 and 30 March - 15 May 1995.

1970's. Stupka and Sharma (1977) showed annual impingement rates at numerous power plant locations for dominant species, and compared to these rates at Pilgrim Station were lower than at most other sites. Recently, Normandeau Associates (1996) compared fish impingement at several marine power plant intakes which demonstrated Pilgrim rates to be among the lowest with the exception of incidents that involve one or two species occasionally. However, in terms of the number of fish species impinged, Pilgrim Station displays a greater variety than most other power plants in the Gulf of Maine area (Bridges and Anderson, 1984a), perhaps because of its proximity to the boreal-temperate zoogeographical boundary presented to marine biota by Cape Cod.

Monthly intake water temperatures recorded during impingement collections at Pilgrim Station were above normal during most of 1998 compared to the mean monthly temperatures for the 10-year interval 1989-1998 (Table 7). During the first half of 1998, with the exception of June, water temperatures were higher than this 10-year period.

Overall 1990/1995/1997/1998 displayed relatively warm water temperatures, 1987/1989/1991 1994/1996 were average years, and 1988/1992/1993 were cold water years. Pilgrim Station intake temperatures approximate ambient water temperatures. However, a dominance of colder water species (i.e., Atlantic silverside, winter flounder, and rainbow smelt) appeared in impingement collections during 1998, with the warmer water species Atlantic menhaden also being well represented.

4.2. Invertebrates

In 575 collection hours, 641+ invertebrates of 12 species (Table 8) were recorded from Pilgrim Station intake screens between January-December 1998. The annual collection rate was 1.11+ invertebrates/hour. Blue mussel dominated, being caught only in August.

Table 7. Monthly Means of Intake Temperature (°F) Recorded During Impingement Collections at Pilgrim Nuclear Power Station, 1989 - 1998

Month	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989	($\bar{X}$) 1989-1998
January	40.5	38. 8	37.1	41.1	28.2	37.3	36.3	37.6	38.4	38.4	37.3
February	39.6	37.4	35.8	36.6	29.2	32.2	34.3	36.7	38.1	42.9	36.1
March	40.1	39.2	37.4	39.5	30.9	35.2	36.5	39.7	37.9	38.4	37.6
April	45.2	44.1	41.8	41.7	37.9	41.2	43.4	44.5	46.6	41.4	43.3
May	51.4	47.8	48.6	48.8	44.3	48.3	51.6	53.8	50.9	48.7	49.5
June	52.6	58.7	56.0	56.4	45.2	52.7	54.2	60.1	53.6	57.4	54.9
July	57.5	60.6	56.1	58.1	56.8	56.8	55.9	61.7	61.2	61.6	58.6
August	57.7	62.3	60.8	67.3	59.3	53.7	60.4	58.5	64.7	59.8	60.6
September	60.0	61.7	62.9	62.4	60.4	50.5	57.4	58.6	63.3	58.6	60.1
October	54.4	55.7	57.5	57.9	63.3	43.9	53.8	52.0	55.1	53.9	55.1
November	49.9	50.8	49.6	50.6	55.8	39.9	50.8	47.9	47.9	45.6	49.2
December	45.3	41.0	45.2	40.3	44.9	34.5	43.1	41.7	42.9	35.6	41.6
Mean											48.7

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Table 8. Monthly Impingement for All Invertebrates Collected from Pilgrim Station Intake Screens, January - December 1998

Species	Jan.	Feb.	March	April	May	June	July	August	Sep.	Oct.	Nov.	Dec.	Total
Blue mussel								*					*
Sevenspine bay shrimp	12	2	310	135								23	482
Longfin squid				1	3	5	1	44	6	3	1		64
Green crab	1		1	2	4	4	1	6	1	8	3	3	34
American lobster					6	2	1		9		4	2	24
Common starfish				1	3			1			4	4	13
Horseshoe crab					2	3	1	1					7
Rock crab				2	1			1			1	2	7
Lady crab				1			2				1		4
<u>Nereis sp.</u>	2	1											3
Green sea urchin							1	1					2
Isopod					1								1
Totals	15	3	311	142	20	14	7	54+	16	11	14	34	641+
Collection Time (hrs.)	26	17	32	67	71	114	64	39	29	43	38	35	575
Collection Rate (#hr.)	0.58	0.18	9.72	2.12	0.28	0.12	0.11	1.38+	0.55	0.26	0.37	0.97	1.11+

*Undetermined numbers

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Sevenspine bay shrimp (Cragon septemspinosa) were captured in greatest numbers in March/April and were 75% of the enumerated catch. Longfin squid (Loligo pealei) and green crab (Carcinus maenus) represented 10.0 and 5.3%, respectively, of the total invertebrates impinged. Unlike the fishes, the 1987 and 1988 invertebrate impingement rates were comparable to 1989 - 1998 despite relatively low circulating water pump capacity available in 1987 and 1988.

A noteworthy occurrence was the collection of so many blue mussels during 1986-1989. This could be an effect of the Pilgrim Station outage during the late 1980s (reduced power level in 1989) which precluded the use of regular thermal backwashes for macrofouling control and the migratory/adhesive abilities of mussels. In 1990 - 1998 several thermal backwashes were performed and blue mussel impingement was relatively minor for those years. During 1998 aggressive biofouling control activities included three effective thermal backwashes during the months of April, July and September.

Longfin squid were the third most abundant invertebrate impinged, peaking in August. Green crabs were fourth, being most represented in October. Twenty -four specimens of the commercially important American lobster were captured in 1998 ranking them fifth. This equals 366 lobsters impinged on an annual basis at 100% operation of Pilgrim Station, under conditions at the times of impingement. This is considerably less than in 1991-1994 and is more comparable to the number of lobsters impinged in most previous years. The lobsters ranged in size from 27-74 mm carapace length and were impinged mostly in September.

Approximately 1,980 pounds of mixed algae species were recorded during impingement sampling, for a rate of 3.44 pounds/hr. This equates to 15 tons of algae annually on Pilgrim intake screens. This rate is considerably higher than the low flow 1984, and 1988 outage years, comparable to 1989-1992 and 1994-1997, and much lower than 1993 which experienced very adverse meterological conditions of high winds and coastal storms (particularly in December).

4.3 Fish Survival

Fish survival data collected in 1998 while impingement monitoring are shown in Table 9. Continuous screenwash collections provided the fewest numbers of fishes and revealed an overall survival rate of approximately 51%. Fishes collected during static screen washes fared worse showing a survival rate of 32%. As in previous years, the lower initial survival rate for static screen washes was influenced by the low initial survival of Atlantic silverside which were impinged in abundant numbers. As illustrated in 1993-1998, fishes have a noticeably higher survival rate during continuous screen washes because of reduced exposure time to the effects of impingement. However, reduced intake currents in 1984, associated with limited circulating water pump operation, may have been a factor in higher static wash survival then because of less stress on impinged individuals; although this wasn't apparent from 1987 and 1988 limited pump operation results.

Among the ten numerically dominant species impinged in 1998, four demonstrated initial survival rates of 50% or greater. Grubby showed 82% survival, winter flounder 86%, alewife 8%, Atlantic silverside 26%, windowpane 72%, rainbow smelt 22%, Atlantic herring 0%, Atlantic menhaden 5%, lumpfish 63%, and blueback herring 12%. Some of these high survival percentages may be explained by the robustness and durability of some of the species that were sampled during screenwashes.

Table 9. Survival Summary for the Fishes Collected During Pilgrim Station Impingement Sampling, January-December 1998. Iniital Survival Numbers are Shown Under Static (8-Hour) and Continuous Wash Cycles

Speicies	Number Collected		Number Surviving		Total Length (mm)	
	Static Washes	Cont. Washes	Static	Cont.	Mean	Range
Atlantic silverside	350	37	80	22	98	70-135
Winter flounder	56	42	43	41	77	39-277
Atlantic menhaden	33	32	2	1	66	46-90
Rainbow smelt	14	37	2	9	107	70-157
Windowpane	21	4	14	4	87	47-291
Lumpfish	17	2	11	1	43	31-80
Grubby	16	1	13	1	62	50-90
Alewife	11	2	0	1	89	68-118
Blueback herring	8	0	1	-	82	66-96
Atlantic herring	6	1	0	0	98	45-275
Hake spp.	4	2	0	0	73	60-117
Atlantic cod	2	3	0	1	57	53-67
Cunner	3	2	2	1	83	46-108
Little skate	4	1	1	0	423	357-485
Red hake	4	0	0	-	93	68-137
Threespine stickleback	3	1	3	1	50	36-62
Radiated shanny	2	1	2	1	97	78-130
Tautog	2	1	2	1	96	75-132
Atlantic tomcod	0	2	-	2	125	120-130
Butterfish	2	0	0	-	47	40-53
Rock gunnel	2	0	1	-	108	67-148
Sand lance sp.	0	2	-	2	139	122-156
Spotted hake	2	0	0	-	76	76
Striped killifish	2	0	0	-	80	75-85
White perch	1	1	1	0	96	92-100
Atlantic moonfish	1	0	0	-	50	50
Bluefish	1	0	1	-	685	685
Fourbeard rockling	1	0	1	-	74	74
Fourspot flounder	1	0	1	-	163	163
Longhorn sculpin	0	1	-	1	328	328
Northern searobin	1	0	0	-	170	170
Scup	1	0	0	-	190	190
Silver hake	1	0	0	-	71	71
Smallmouth flounder	1	0	0	-	52	52
Striped cusk-eel	0	1	-	0	192	192
Summer flounder	1	0	0	-	365	365
All Speicies Number (% Surviving)	574	176	181 (31.5)	90 (51.1)		

SECTION 5

CONCLUSIONS

1. The average Pilgrim impingement rate for the period January-December 1998 was 1.30 fish/hour. The impingement rates for fish in 1984, 1987, and 1988 were several times lower than in 1989-1998 because of much reduced circulating water pump capacity during the former years.

2. Thirty-six species of fish were recorded in 575 impingement collection hours during 1998. In 1989-1998 several times the number of fishes were sampled as compared to 1984 and 1988, despite more collection hours in 1984 and an average number of hours in 1988. This illustrates the importance that the number of circulating pumps operating has on the quantity of impinged organisms. Substantially less collecting hours for portions of 1987 precluded its comparison with other years.

3. At 100% yearly operation the estimated maximum January-December 1998 impingement rate was 11,426 fishes. This projected annual fish impingement rate was much lower than most recent years' rates because of several impingement incidents during the past few years.

4. The major species collected and their relative percentages of the total collections were Atlantic silverside, 51.6%; winter flounder, 13.1%; Atlantic menhaden, 8.7%; and rainbow smelt, 6.8%.

5. The peak in impingement collections occurred during March/April when 89% of the annual catch of Atlantic silverside occurred.

6. Monthly intake water temperatures, which generally reflect ambient water temperatures, were higher for 1998 than the ten-year monthly averages for the period 1989-1998, with the exception of June-October, which were lower than normal.

7. The hourly collection rate for invertebrates was 1.11+. Blue mussel dominated in August. Sevenspine bay shrimp were second because of relatively large early spring collections. Longfin squid and green crab were 10.0 and 5.3% of the enumerated catch. Twenty-four American lobsters were collected which equates to a potential 1998 impingement of 366 lobsters.

8. Impinged fish initial survival was approximately 32% during static screen washes and 51% during continuous washes for pooled species. Of the ten fishes impinged in greatest numbers during 1998, four showed initial survival rates of 50% or greater.

SECTION 6

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The Commonwealth of Massachusetts
Division of Marine Fisheries
50A Portside Drive
Pocasset, MA 02559

HILIP G. COATES
DIRECTOR

617-727-0394
508-563-1779
Fax: 508-563-54

MEMORANDUM

TO: Members of the Administrative-Technical Committee, Pilgrim Power Plant Investigations
FROM: Brian Kelly, Acting Recording Secretary
SUBJECT: Minutes from the 90th Meeting of the A-T Committee
DATE: September 22, 1998

The 90th meeting of the Pilgrim A-T Committee was called to order by Chairman Szal at 9:55 AM on September 15, 1998, at the National Marine Fisheries Service lab in Narragansett, Rhode Island.

Minutes of the 89th Meeting

Bob Maietta motioned to accept the minutes of the last meeting, while Jack Parr seconded the motion, which was carried unanimously.

Pilgrim Station Status Update

Bob Anderson noted that 1998 is shaping up to be a record year for Pilgrim Station regarding power output capacity. There is a planned refueling outage slated for April 1999. The sale of Pilgrim Station should occur in early October 1998. Final nuclear license transfer will take an additional 6-12 months, pending NRC approval. The new owner may want to build another generating unit at the present Pilgrim site.

1999 Marine Fisheries Monitoring (outlined in DMF's August 26, 1998 memorandum)

Bob Lawton mentioned that he felt strongly that the restoration/enhancement part of the upcoming Division of Marine Fisheries (DMF) work is the most important part of his proposal, and the means of procuring and setting aside the funding for these efforts are critical.

Regarding field work, Bob described the proposed effort of continuing smelt restoration using egg trays in the Jones River and by monitoring smelt spawning in several other tributaries of Plymouth, Kingston, Duxbury Bay. Several A-T members requested that DMF monitor the Jones River obstruction cleanup rendered by students from Silver Lake Regional High School, so as to maintain the physical/biotic diversity of the stream while maintaining unobstructed passage for spawning smelt.

The winter flounder abundance study was presented next, with DMF proposing a stratified, area swept, bottom trawl survey, with Adult Equivalent model numbers resulting from plant entrainment [generated by Marine Research, Inc. (MRI)] to be compared to the index of adult abundance. There was considerable discussion regarding the Adult Equivalency model, the rationale for post-stratifying the trawl survey, Eric Adams' hydrodynamic modeling of larval flounder dispersal in the Pilgrim area, and the utility of this survey. Overall, the Committee felt that there was a need for estimating adult flounder abundance in the Pilgrim area.

Lastly, Bob outlined the observational SCUBA dive schedule for the discharge area. Bob mentioned that with his proposed work, BECo would save approximately 90 thousand dollars as compared to last year. Jack Parr motioned that the proposed 1999 field work be done as outlined by DMF (sole-source). Gerry Szal seconded the motion, which passed unanimously. Jack Parr also recommended to the Committee that regarding upcoming review processes at other plants that, when possible, regulatory agencies should be involved in the collection or the oversight of the collection of monitoring data, in order to insure quality control and assurance.

Bob then outlined DMF sampling programs that have not been summarized in the final report series, with his recommendation of which reports should have priority as far as their utility and value. Bob Maietta motioned that the Committee accept the DMF recommendation of writing three final reports in 1999 - cunner recruit surveys, winter flounder population study, and rainbow smelt restoration. Jack seconded the motion, which passed unanimously. Jack also requested that DMF produce a one page comment/fact sheet on each of the other DMF studies that will not have a final report done on them, noting each study's merit from a general utilitarian approach (e. g., potential value to perform a similar monitoring study at other power plants).

Lastly, the Committee had a lengthy discussion on the proposed pilot restoration/enhancement program for Pilgrim. It began with Jack discussing the Essential Fish Habitat (EFH) Amendment to the Stevens-Magnuson Fishery Conservation and Management Act, which concentrates on habitat protection and conservation, with the role of the regional Fisheries Management Councils as custodians of this section; habitat is defined as that essential for all fish life stages. As power plant impacts (entrainment, impingement and thermal) are mentioned in this document, power companies must now realize that EPA, as a permitting agency, must meet the Fisheries Management Council EFH mandate here, which has regulatory backing.

Bob Lawton then followed with the DMF restoration/enhancement proposal, which would appear to fit in well with the new EFH mandate. Bob Anderson noted concerns of BECo due to increased electric utility competitiveness and hence cost considerations in the industry from deregulation. Bob Maietta and Jack Parr noted that in light of the amendment to the Stevens-Magnuson Act, the timing is appropriate to seek some type of restoration/compensation/remediation fund from utilities. Jack mentioned that consent decrees, basically negotiated settlements between utilities and regulatory agencies as part of the permitting process, have been agreed upon in some environmental restoration/enhancement cases. The Committee decided that a letter addressed to BECO regarding this issue will be drafted by Gerry Szal and Jack Parr to be signed by Jane Downing, who is the Director of the Massachusetts Office of Ecosystem Protection at the EPA Boston office. In that letter will be a requested dollar amount for proposed restoration/enhancement. This is partially justified by the fact that DMF has reduced substantially its 1999 monitoring budget. Jack noted that regulators may be reaching the point where when a NPDES permit comes up for renewal, EPA may decide to adjust up or down monitoring efforts, request restoration/enhancement, and evaluate the effectiveness of respective restoration efforts.

IV. 1999 Benthic Monitoring Program

Bob Maietta motioned to accept the proposed benthic monitoring program by ENSR which includes one qualitative transect discharge dive in September and a multi-year final benthic impact analysis report outlined in ENSR's August 26, 1998 memorandum. The motion was seconded by Gerry Szal, which then passed unanimously.

V. 1999 Impingement and Entrainment Monitoring

Mike Scherer reviewed Pilgrim Station monitoring proposed by MRI. Mike also discussed the statistical power/cost analyses done by MRI regarding impingement and entrainment sampling at Pilgrim Station. The Committee felt the current level of impingement and entrainment sampling (three times a week) is acceptable for now to monitor potential plant impact. Jack asked Mike to generate statistical power versus rate of population change graphs for him for several species. The Committee discussed general entrainment monitoring requirements for other plants in their upcoming relicensings. Bob Maietta motioned that MRI continue sole source with the proposed 1999 entrainment/impingement work at Pilgrim Station as outlined in MRI's August 28 1998 memorandum. The motion was seconded by Gerry, which passed unanimously.

VI. Other Business

Bob Anderson motioned that BECo not have the discharge barrier net in place in 1999 unless requested to do so in an emergency. Gerry Szal seconded the motion which passed unanimously. A discussion of past menhaden kills at the plant and the utility of barrier nets ensued.

VII. The meeting adjourned at 3:15 P.M.

PNPS A-T Committee Meeting Attendance

September 15, 1998

Gerald Szal, Chairman	Mass. DEP, Worcester
Robert Anderson	Boston Edison Company
Carolyn Griswold	NMFS, Narragansett
Robert Lawton	Mass. DMF, Pocasset
Robert Maietta	Mass. DEP, Worcester
Jack Parr	US EPA, Lexington
Michael Scherer	MRI, Falmouth
Richard Zeroka	Mass. CZM, Boston
Brian Kelly	Mass. DMF, Pocasset Acting Recording Secretary

PILGRIM NUCLEAR POWER PLANT

ADMINISTRATIVE-TECHNICAL COMMITTEE

September, 1998

Robert D. Anderson
Boston Edison Company
Pilgrim Nuclear Power Station
600 Rocky Hill Road
Plymouth, MA 02360-5599
(508) 830-7935
FAX (508) 830-8575

W. Leigh Bridges
MA Division of Marine Fisheries
State Office Building
100 Cambridge Street
Boston, MA 02202
(617) 727-3194

Carolyn Griswold
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882
(401) 782-3273

John Boardman
MA Division of Marine Fisheries
50A Portside Drive
Pocasset, MA 02559
(508) 563-1779

Robert Lawton
MA Division of Marine Fisheries
50A Portside Drive
Pocasset, MA 02559
(508) 563-1779 x 118

Robert Maietta
DEP-Division of Watershed Management
627 Main Street, 2nd Floor
Worcester, MA 01608
(508) 767-3793

Dr. Martha Mather
MA Coop Fish & Wildlife Unit
Holdsworth Hall
University of Massachusetts
Amherst, MA 01003
(413) 545-4895

Jack Paar
U. S. Environmental Protection Agency
New England Regional Lab
Surveillance and Analysis
60 Westview Street
Lexington, MA 02173
(781) 860-4604

Nicholas Prodany
U.S. Environmental Protection Agency
Region 1, Industrial Permits Section
JFK Federal Building
Boston, MA 02203
(617) 565-3587

Rick Zeroka
MA Coastal Zone Management
100 Cambridge Street, Floor 20
Boston, MA 02202
(617) 727-9530

Gerald Szal
DEP-Division of Watershed Management
627 Main Street, 2nd Floor
Worcester, MA 01608
(508) 767-2789

<u>OTHER CONTACTS</u>

Dr. James Blake/Izzie Williams
ENSR Consulting and Engineering
89 Water Street
Woods Hole, MA 02543
(508) 457-7900
FAX (508) 457-7595

Derek McDonald
Marine Biofouling Control Corp.

(508) 888-4431

Dr. Michael Scherer
Marine Research Inc.
141 Falmouth Heights Road
Falmouth, MA 02540